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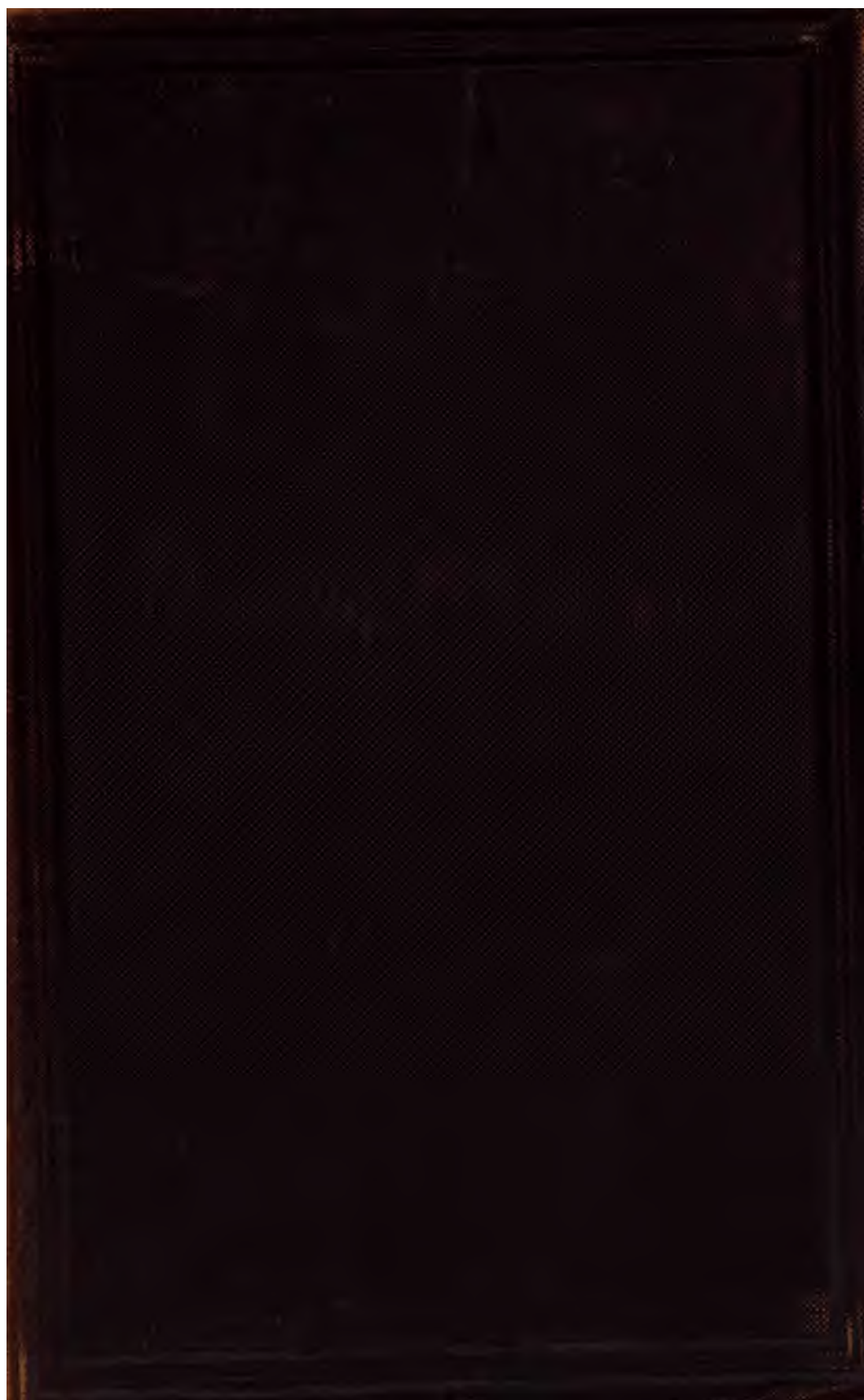
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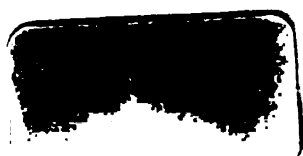




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ELEMENTARY SURVEYING;
COMPRISING A
COURSE OF LAND SURVEYING
WITH GUNTER'S CHAIN,
AND THE
PRACTICE OF SURVEYING WITH THE THEODOLITE,
POCKET-SEXTANT, AND PRISMATIC COMPASS;
TOGETHER WITH A SECTION ON
LEVELLING.

BY MAJOR BASIL JACKSON,
PROFESSOR OF MILITARY SURVEYING AT THE HON. EAST INDIA COMPANY'S
MILITARY COLLEGE.

LONDON:
SIMPKIN AND MARSHALL, STATIONERS' HALL COURT.

1842.

970 .



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PALMER AND CLAYTON, PRINTERS,
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AN ADDRESS
TO
PROPRIETORS OF ACADEMIES IN GENERAL.

GENTLEMEN,

THE immense strides which mechanical science has made of late years, have opened a vast field for talent and enterprise in the profession of Civil Engineering; but I cannot perceive that any corresponding impulse has hitherto been communicated to early education in our private academies. Take, for example, the art of Practical Surveying, a knowledge of which is required by all Civil Engineers, as well as being highly useful to Land-holders, Emigrants, Travellers, Sailors, Soldiers, Architects, &c. &c.

Now, I have reason to think that instruction in this important branch of useful education is not afforded in half a dozen seminaries throughout the empire: at least my own experience has led me to this conclusion; since, during five years that

I have conducted the Military Surveying department at the Hon. East India Company's Military College, I can with truth assert that scarcely one cadet in twenty, on entering the institution, has known the length of Gunter's chain.

The little manual on Surveying now offered to your notice, owes its existence to the desire expressed in the following extract of a letter from an enlightened member of your own body:—

“ I have taken up this branch of study (surveying) on account of my increasing connexion with India, where both civil and military surveying must be important. I have several copies of your new and improved edition.* You have handled your subject in a clear common sense style: but you will pardon me for suggesting another edition for the use of schools, at the price of about four or five shillings, to be used as a text-book, with copious examples for practice. The military and civil branches might be combined, and an article given on levelling. From what I have seen of your works, I am sure you would produce just the book that would meet the wants of those who are training engineers.”

In accordance with the views of my correspondent, I have given a limited, but sufficient course of

* A Course of Military Surveying, &c.; published by W. H. Allen and Co., 7, Leadenhall-street.

linear surveying, as practised by land surveyors at present, which is followed by full explanations of the methods of surveying with instruments; being of opinion that, besides common land measuring (as I have observed at page 86), pupils ought to receive instruction in methods of surveying of general application, suited alike to all countries, whether mountainous or flat, wooded or bare, open or enclosed. Whereas the practice of *linear surveying* is only adapted to a country which is neither mountainous nor thickly wooded; and would therefore be almost useless if applied amidst the Alps or Pyrenees, the forests of America, or jungles of India. Besides, even under the most favourable circumstances as regards country, chain surveying is of necessity limited to an extent of a few square miles, and is moreover wholly inapplicable to the surveying of roads and rivers. All extensive surveys of whatsoever nature, and all maps and plans required for geographical purposes, must be made with the aid of instruments for measuring angles; such as the theodolite, sextant, compass, &c.

My object in compiling this little manual has been to simplify surveying, so as to bring the

practice of it within the power of any assistant master of mathematics attached to a school; thus obviating the necessity of having recourse to a professional surveyor. And as the book is published at a very low price, considering the number of plates and diagrams which it contains, I trust it will conduce to spread amongst our schools the desire to cultivate extensively a branch of education so generally useful as surveying.

I am, Gentlemen,

Your very obedient Servant,

BASIL JACKSON.

NOTICE.

THE object of publishing the following short Treatise is to facilitate the acquirement, by Students at an early age, of the principles and practice of Surveying.

The section on Land-Surveying will be found to comprise the most approved methods both by means of the Chain and Cross-staff, and with the Chain alone, as practised by English surveyors.

The sections on Surveying with Instruments are intended to convey an accurate knowledge of the Theodolite, Prismatic Compass, and Pocket Sextant, and of the methods of making surveys with them for Geographical, Nautical, or Military purposes; the examples given are therefore not strictly designed for mere land-surveying. At the same time, the author ventures to offer as his opinion, that our Civil Surveyors would often greatly abridge their labours by a more general use of the above mentioned Instruments, together with the Optical Square for determining perpendiculars, and setting off right-angles.

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PRELIMINARY REMARKS.

“WHOSOEVER considers the whole extent and depth of Geometry, will find that the main design of all its speculations is mensuration. To this the Elements of Euclid are almost entirely devoted, and this has been the end of the most laboured geometrical disquisitions of either the ancients or moderns.

“Now the whole mensuration of figures may be reduced to the measure of triangles, which are always the half of a rectangle of the same base and altitude, and, consequently, their area is obtained by taking half the product of the base multiplied by the altitude.

“By dividing a polygon into triangles, and taking the value of these, that of the polygon is obtained; by considering the circle as a polygon with an infinite number of sides, we obtain the measure thereof to a sufficient degree of accuracy.

“The theory of triangles is, as it were, the hinge upon which all geometrical knowledge turns.”—ADAMS’s *Geometrical Essays*.

To the Surveyor, triangles are everything: no matter whether the survey be a field, an estate, or a kingdom, triangulation alone will lead him to a satisfactory result.

The study of geometry cannot, therefore, be too strongly insisted on; and it is to be regretted that youth are not earlier taught the elements of a science of such great importance. But we should not allow ourselves to be carried away by the notion that this study must necessarily precede practice in ordinary surveying, especially common land-surveying. Let pupils be able to handle their mathematical instruments, and do a few of the easiest geometrical problems upon paper; take them then to the field, and render all after instruction as practical as possible.

SECTION I.

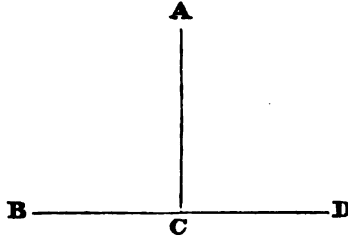
A SELECTION OF DEFINITIONS IN GEOMETRY, USEFUL TO
THE SURVEYOR.

1. THE science which treats of magnitude in general is styled GEOMETRY.
2. MAGNITUDE, or EXTENSION, comprehends length, breadth, and thickness.
3. The purpose of SURVEYING is to obtain superficial measurement, or length and breadth.
4. A *point* has position, but not magnitude.
5. A *line* has length, but not magnitude.
6. The extremities of a line are points, and the intersection, or crossing of one line with another, also forms a point.
7. A straight line is that which lies *evenly* (Euclid) between its extreme points or ends.
8. All lines are either straight lines or curve lines.
9. An *angle* is formed by the meeting of two straight lines at a point, C.



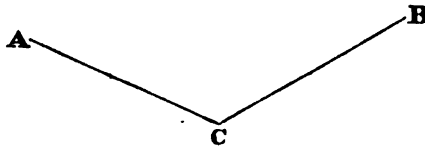
10. When a straight line, A C, standing upon another, D B, makes angles, A C B and A C D, on each side equal to one another, each of these angles is called a *right angle*;

and the line AC is said to be *perpendicular* to the line BD .

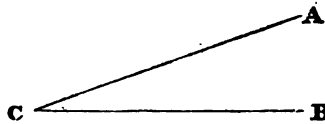


Angles are commonly expressed by three letters, of which the one at the angular point is always placed in the middle; as C in the angle ACB .

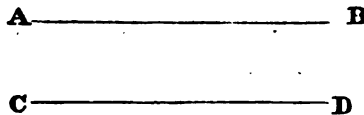
11. An *obtuse* angle, ACB , is greater than a right angle.



12. An *acute* angle, ACB , is less than a right angle.

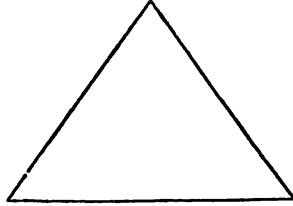


13. Parallel lines are those which have no inclination towards each other, or which are everywhere equi-distant, as AB and CD .

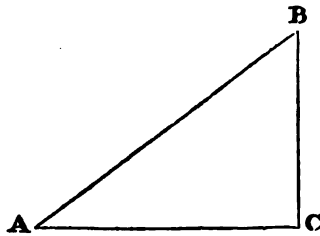


14. A *plane triangle* is a figure bounded or formed by

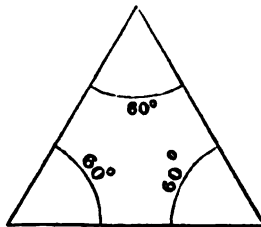
three straight lines ; it has, therefore, three sides and three angles.



15. A *right-angled* triangle is that which has one right angle, $A C B$. The longest side of a right-angled triangle is called the *hypotenuse*; thus $A B$ is the hypotenuse of the right-angled triangle $A C B$.



16. An *equilateral* triangle has three equal sides, and three equal angles.



17. An *isosceles* triangle has only two of its sides equal.

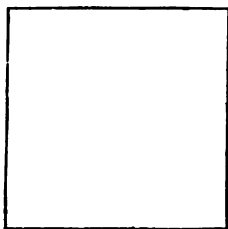
18. A *scalene* triangle has all its sides unequal.

19. The three angles of a triangle, taken together, are equal to two right angles ; and if one angle of a triangle be

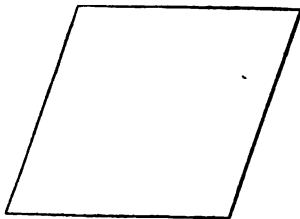
a right angle, the other two angles taken together will be equal to a right angle.

20. All plane figures, bounded or formed by four right lines, are called *quadrangles*, or *quadrilaterals*.

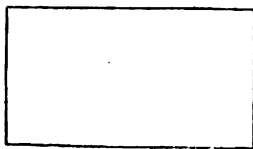
21. A *square* is a quadrangle, whose sides are all equal, and its angles all *right* angles.



22. A *rhombus* is a quadrangle, whose sides are all equal, but its angles not right angles.



23. A *parallelogram* is a quadrangle, whose opposite sides are parallel.

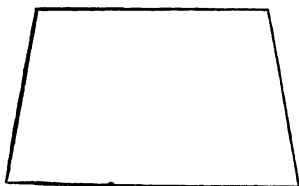


24. A *rectangle* is a parallelogram, whose angles are all right angles.

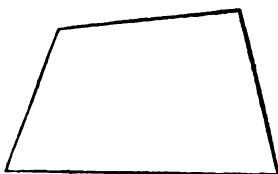
25. A *rhomboid* is a parallelogram, whose angles are not right angles.



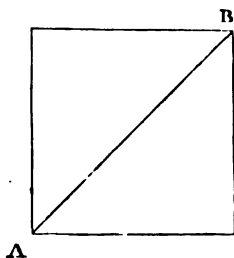
26. A *trapezoid* has four sides, two of which are parallel.



27. A *trapezium* has four sides, no two of which are parallel.



28. A right line, joining any two opposite angles of a four sided figure, is called a *diagonal*; and divides the figure into two triangles. Thus, A B is a diagonal.



29. All plane figures, having more than four sides, are called *polygons*.

Polygons, of five sides, are called *pentagons*; those, having six, *hexagons*; with seven, *heptagons*; with eight, *octagons*; with nine, *nonagons*; with ten, *decagons*; with eleven, *undecagons*; with twelve, *dodecagons*.

30. A *regular polygon* is that whose sides and angles are all equal.

31. The *base* of any figure is that side on which it is supposed to stand; and the *altitude* is the perpendicular falling upon the base, from an angle opposite.

Note.—Should the perpendicular fall beyond the figure, in consequence of the figure leaning on one side, the base must be prolonged to meet it.

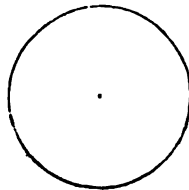
32. Triangles upon the same base, and between the same parallels, are equal, or enclose the same space.

33. Parallelograms standing on the same base, and being between the same parallels, are equal.

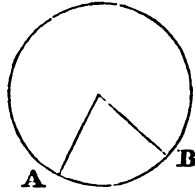
34. Parallelograms having the same base, and equal altitudes, are equal.

35. If a triangle and parallelogram have equal bases, and equal altitudes, the triangle is half the parallelogram.

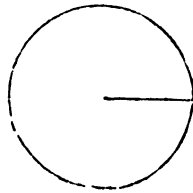
36. A *circle* is a plane figure bounded by a curve line, called its circumference, which is everywhere equally distant from a point within it, called the centre.



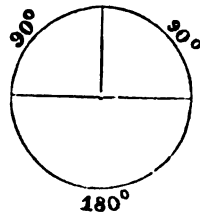
37. Any part of the circumference of a circle is called an *arc*. Thus, AB is an arc.



38. Any right line drawn from the centre of a circle to its circumference, is called a *radius*; and all radii of the same circle are equal.

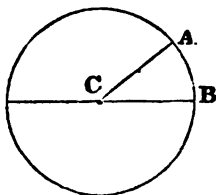


39. The circumference of every circle is supposed to be divided into 360 equal parts, called *degrees*; each degree into 60 *minutes*; and each minute into 60 *seconds*. The fourth part of a circle is called a *quadrant*, and contains 90 degrees, being the fourth part of 360 degrees. A semi-circle contains 180 degrees.



40. It is with the aid of the circle that angles are measured; for we say that an angle contains a certain number of degrees, minutes, and seconds; by which we

understand that if a circle be described round the angular point as a centre, the arc, or portion of the circumference contained between the two lines forming the angle, is the measure of the angle. Thus the measure of the angle ACB , is the arc AB , reckoned in degrees, minutes, and seconds.



A right angle contains 90 degrees, because it is measured by a quadrant, or the fourth part of a circle of 360 degrees.

41. It has been stated (see 19), that the three angles of a triangle taken together, are equal to two right angles. They are therefore equal to 180 degrees; hence, if in a *right-angled* triangle we know the measure of one of its two *acute* angles, we have only to add to it 90 degrees, and then subtract the sum from 180 degrees; when the remainder will be the measure of the third angle. In a right-angled triangle, the sum of its two acute angles is 90 degrees.

° is the mark of degrees.

' „ „ minutes.

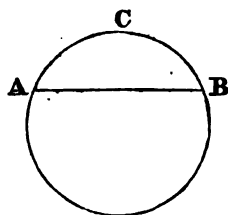
" „ „ seconds.

Thus, $4^{\circ} 10' 12''$, signify 4 degrees, 10 minutes, 12 seconds.

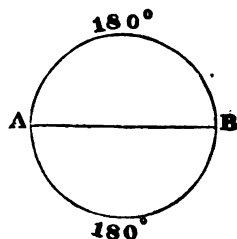
42. The *complement* of an angle or arc, is its difference from 90° , or a right angle. The *supplement* of an angle or arc, is its difference from 180° , or two right angles.

43. The *chord* of an arc is a right line joining the two

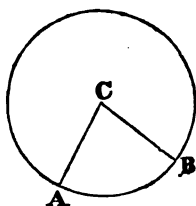
extremities of that arc; thus the line AB is the chord of the arc ACB .



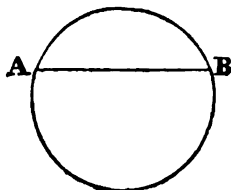
44. A *diameter* of a circle is a chord AB , passing through its centre, and forming two semicircles, each containing 180° .



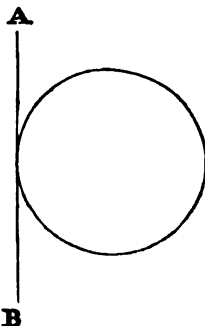
45. A *sector* is any part of a circle bounded by an arc, and two radii drawn to its extremities. Thus, if C be the centre, ACB is the sector.



46. A *segment* is any part of a circle cut off by a chord. Thus AB divides the circle into two segments.



47. A *tangent* is a right line, touching the circumference without cutting off any portion of a circle. Thus A B is a tangent.



EXPLANATION OF CERTAIN SIGNS.

48. The following signs are in general use, and contribute greatly to distinctness as well as to the abbreviation of language :—

- + *plus*, or *added to*, placed between two numbers or letters denoting an angle, triangle, &c., signifies that they are to be added together. Thus $6+5$ denotes that 5 is to be added to 6.
- *minus*, or *less by*, between two numbers, &c., signifies that the second number is to be taken from the first. Thus $6-5$ denotes that 5 is to be taken from 6.
- × *multiplied by*, placed between two numbers, signifies that they are to be multiplied together. Thus 6×5 denotes that 6 is to be multiplied by 5.
- ÷ *divided by*, placed between two numbers, signifies that the first number is to be divided by the second. Thus $12 \div 3$ denotes that 12 is to be divided by 3.
- = *equal to*, signifies that the two numbers, or letters, expressing an angle, triangle, &c., between which it is placed are equal to one another. Thus $6+3=9$.

Let the beginner read off the following :

Angle ABC + angle DEF = angle GHK — angle LMN.

A SELECTION OF THE MOST USEFUL GEOMETRICAL PROBLEMS, SHOWING THE MANNER OF TRACING THE FIGURES BOTH ON PAPER AND THE GROUND.

Geometrical figures are traced as easily on the ground as upon paper; there is, however, a difference in the mode of operation, because the instruments employed are different. A rod, chain, or measuring tape, is used instead of a scale of equal parts; the spade instead of a pencil; a cord fastened to two staves, and drawn tight, instead of a ruler; the same cord, by fixing one of the staves in the ground, and keeping the other moveable, answers the purpose of a pair of compasses; and with these simple instruments, every geometrical figure necessary in practice may be easily traced on the ground.

49. *To draw upon the ground a straight line through two given points.*

Plant a picket, or staff, at each of the given points, then fix another between them, in such a manner, that when the eye is placed at the edge of one staff, the edges of the other two may coincide with it. The line may then be prolonged by fixing up other staves. The accuracy of this operation depends greatly on fixing the staves upright, and not letting the eye be too near the staff from whence the observation is made.*

* What we call a straight line on the ground, is rarely in accordance with Euclid's definition (7); nor can it be so, unless the ground be either perfectly level, or have an exact slope.

50. *To walk in a straight line from a proposed point to a given object.*

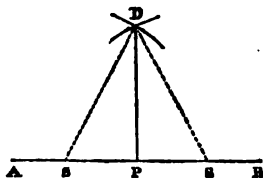
Fix upon some point, as a bush, or a stone, or any mark that you find to be in a line with your given object, and walk forward, keeping the two objects strictly in line; selecting a fresh mark when you come within 20 or 30 paces of the one upon which you have been moving. Observe, that to walk in a direct line, it is always necessary to have two objects constantly in view.

51. *To trace a line in the direction of two distant points.*

Let two persons separate to about 50 or 60 paces; then, by facing each other, and alternately motioning to move right or left, they soon get exactly into line with the distant object; or, for greater accuracy, they may hold up staves.

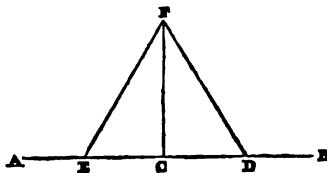
52. *At a given point P in a right line AB, to raise a perpendicular PD, to that line.*

On each side of P, take equal distances SP, PS, and on SS as centres, with any opening of the compasses greater than the distance SP, sweep arcs or curves, which will cross each other at D; then draw PD for the perpendicular required.



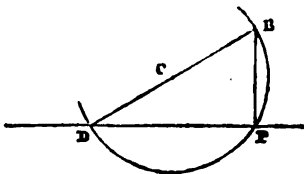
53. *To perform the same operation on the ground.*

Set off two points E and D, equally distant from C; double a cord into two equal parts, and fasten the ends at E and D; take the middle of the cord in the direction of F, and draw tight; then will CF be the required perpendicular.



54. *When the point is near the end of a line.*

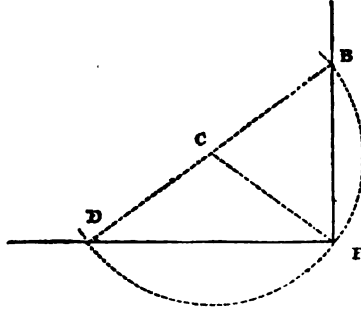
Fix on any convenient point C above the line, and with a radius, or opening of the compasses equal to the distance CP, trace a circle, or part of a circle, whose circumference shall pass through the point P, and also cut the given line at a point D; then draw a line from D, passing through C, and cutting the circle at B; join BP, which will be the perpendicular required.



55. *The same operation is thus performed on the ground.*

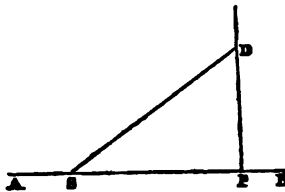
Take, DP, of a convenient length—say twenty feet; then with a cord of any greater length—say thirty feet, fasten one end at D, the other at P, and draw the middle of the cord tight, which will fix a point C; carry the end of the cord, at P, round to B, and draw tight, in the direc-

tion of CD ; fix a pin or stake at B , then shall a line from P to B be perpendicular to DP .



56. *But the quickest way of performing the operation, is by means of the measuring tape; and the numbers 3, 4, and 5, or any multiple of them.*

Suppose, a perpendicular is required to be raised from a point P on the line AB , with the numbers 12, 16, and 20; then $12+16+20=48$, the length of tape required. From P set off 16 feet to S , and there fix an arrow passing through the ring of the tape; place an arrow also at P , and pass the tape round it: then, if the 48th division of the tape be held at S , while a person holding it at the 28th division, draws the three parts of the tape tight, he will fix the point D in a line perpendicular to AB .



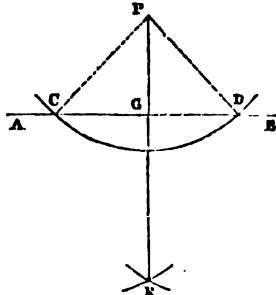
57. *To draw a line on the ground, parallel to another line, and at a given distance from it.*

Raise two perpendiculars to the given line, upon which measure off the given distance; and a line joining those points will be the required line.

A similar process will answer on paper; but a parallel ruler, or a small flat ruler, together with one of a triangular form (see 91), saves us the trouble.

58. *From a given point, P, to let fall a perpendicular, P G, upon a given line, A B.*

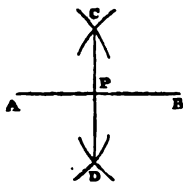
About P, as a centre, with any radius, P D, greater than the distance of P from the line A B, describe an arc, D C; and from D and C, with any radius greater than half, D C, describe arcs, cutting each other in R; join P R: then P G is the perpendicular required.



The process may be somewhat shortened on the ground, by stretching a cord between C and D, then double the cord, which will give the length, C G; and, consequently, fix the point, G, which is the object of the operation.

59. *To bisect or divide into two equal parts, a given line A B.*

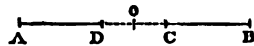
With any opening of the compasses greater than half the given line, about the extremities A and B as centres, describe arcs, intersecting each other in C and D: then draw C D, and it will bisect A B in the point P.



In this manner a line may be divided into 4, 8, 16, &c., equal parts: thus, A P, B P bisected, give 4 equal parts; and those again bisected, would make 8; and so on.

On the ground, if the line be short, stretch a cord along it, then double it for the division.

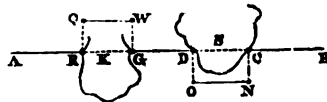
60. The most expeditious method of finding the middle of a long line on the ground, is to measure equal distances from its extremities.—Thus, suppose A and B are the ends of the line, and that A D, B C (found by measuring from



A and B), are each 340 links; and the remaining part, D C, is 42 links: then O, the middle of the line, will evidently be 21 links from D or C.

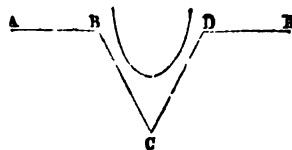
61. In measuring lines or distances on the ground, it sometimes may be necessary to take off-sets, when obstacles fall in the way.

Suppose A and B are the extremities of a line to be measured; and that K and S are pools of water or swamps. Having set up marks at R, G, D, C, in the line A B,



measure equal off-sets, C N, D O; and G W, R Q, at right angles to A B; then Q W and O N may be measured instead of R G and D C.

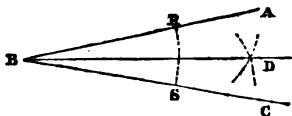
62. When working with an instrument for measuring angles, a more convenient method is to measure, on a line



making an angle of 60° with the original deviation, a distance sufficient to clear the obstacle, and to return to the line at the same angle; the distance, BD , is then equal to either of these measured lines.

63. *To bisect a given right-lined angle, ABC .*

With any convenient radius, BS , about the angular point B as a centre, describe an arc, SR , and from the centres S, R , with any radius longer than half the distance

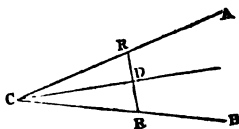


between those points, describe two other arcs, intersecting one another in D ; then the line joining B and D will bisect the angle ABC , and the arc SR .

By such bisections, an angle, or its corresponding arc, may be divided into 2, 4, 8, &c., equal parts. A quadrant, or an angle of 90° , may thus be divided and subdivided, until each arc subtends an angle of only a few minutes. Such a division is readily performed, if the radius is 5 or 6 inches; and will be found convenient for measuring the degrees of an angle when the usual instruments for that purpose are not at hand.

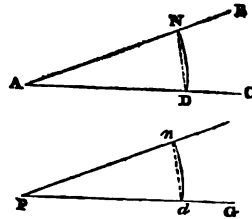
64. *To bisect an angle, ACB , on the ground.*

Measure equal distances CR, CB , from the angular point C : then D , the middle of the cross distance RR , gives the direction of the line CD , which bisects the angle.



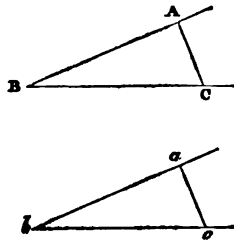
65. *At a given point P, in a right line PG, to make an angle, nPG , equal to a given right-lined angle, BAC.*

About A and P, with the same radius, describe arcs DN and dn ; take dn equal to DN, and draw Pn ; then the angle nPd is equal to the angle NAD, or BAC.



66. *On the ground.*

Set off any number of equal parts from B to C and from B to A, and with the same parts measure AC; describe on



the ground with these three lengths a triangle, abc , and the angle abc will be equal to the angle ABC.

67. When it is proposed to make an angle which shall contain a given number of degrees, &c., a *protractor*, *line of chords*, or a *sector*, will be necessary.

The common protractor is a semi-circular instrument for measuring and laying down angles. The arc or limb is divided into 180 equal parts or degrees; and when its centre is placed over the intersection of two lines, the

A SELECTION OF THE MOST USEFUL GEOMETRICAL PROBLEMS, SHOWING THE MANNER OF TRACING THE FIGURES BOTH ON PAPER AND THE GROUND..

Geometrical figures are traced as easily on the ground as upon paper; there is, however, a difference in the mode of operation, because the instruments employed are different. A rod, chain, or measuring tape, is used instead of a scale of equal parts; the spade instead of a pencil; a cord fastened to two staves, and drawn tight, instead of a ruler; the same cord, by fixing one of the staves in the ground, and keeping the other moveable, answers the purpose of a pair of compasses; and with these simple instruments, every geometrical figure necessary in practice may be easily traced on the ground.

49. *To draw upon the ground a straight line through two given points.*

Plant a picket, or staff, at each of the given points, then fix another between them, in such a manner, that when the eye is placed at the edge of one staff, the edges of the other two may coincide with it. The line may then be prolonged by fixing up other staves. The accuracy of this operation depends greatly on fixing the staves upright, and not letting the eye be too near the staff from whence the observation is made.*

* What we call a straight line on the ground, is rarely in accordance with Euclid's definition (7); nor can it be so, unless the ground be either perfectly level, or have an exact slope.

50. *To walk in a straight line from a proposed point to a given object.*

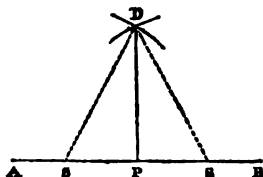
Fix upon some point, as a bush, or a stone, or any mark that you find to be in a line with your given object, and walk forward, keeping the two objects strictly in line; selecting a fresh mark when you come within 20 or 30 paces of the one upon which you have been moving. Observe, that to walk in a direct line, it is always necessary to have two objects constantly in view.

51. *To trace a line in the direction of two distant points.*

Let two persons separate to about 50 or 60 paces; then, by facing each other, and alternately motioning to move right or left, they soon get exactly into line with the distant object; or, for greater accuracy, they may hold up staves.

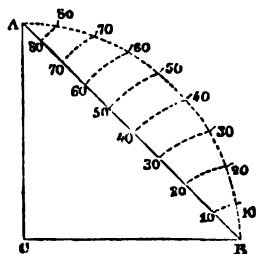
52. *At a given point P in a right line AB, to raise a perpendicular PD, to that line.*

On each side of P, take equal distances SP, PS, and on SS as centres, with any opening of the compasses greater than the distance SP, sweep arcs or curves, which will cross each other at D; then draw PD for the perpendicular required.



number of degrees in the angle is shown by the intercepted arc on the divided edge of the instrument. A protractor for the same purpose is frequently cut on the common plain scales, the centre being on one edge and the graduations on the other.

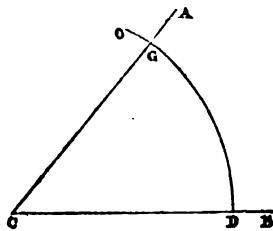
A line of chords is made by transferring the divisions on the arc of a quadrant to its chord. Thus, suppose ACB is a quadrant, and the right line, BA , the chord of its arc.



Let this arc be divided into 90 equal parts or degrees: then, if one foot of a pair of compasses be kept on the point B , and arcs successively described with the other from each of the 90 divisions on the arc to meet BA , those arcs will divide it into a line of chords.

68. *To measure an angle with the line of chords.*

Suppose the angle ACB . With the radius CD , equal to the extent of 60° on the line of chords, about the angular



point C as a centre, describe the arc DO ; then the extent from D to G , measured on the line of chords, gives the

number of degrees, &c., contained in the angle: which in this example is about 51° .

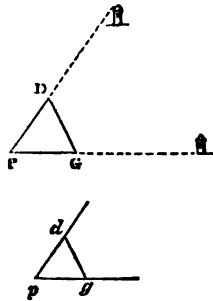
Hence, the method of laying down an angle which shall contain a proposed number of degrees, is obvious. Suppose, for example, it is required to make the angle ACB of 40° : CB being a given line. With C D, the chord of 60° , describe an arc, DO , as before: then 40° , taken on the same line of chords, will extend from D to the point G in the arc, through which the line, CA , must be drawn, to form the required angle.

When the angles are greater than 90° , measure, or lay them off, at twice. Or produce one side, so as to form two angles at the angular point, and then measure the supplement to 180° .

A line of chords is marked on the plain scale furnished in a case of mathematical instruments.

69. *To determine nearly the angle formed by a point, and two distant objects.*

To ascertain the angle DPG , formed by two distant objects and an angular point P , measure equal distances PD , PG , and the cross distance DG ; then construct a

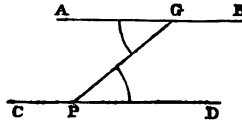


triangle dpg on paper, similar to DPG , and measure the angle p with a protractor, or the chords. Thus, if PD ,

PG , are each 30 feet, and $DG = 28\frac{1}{2}$ feet, the triangle dpg constructed with 30, 30, $28\frac{1}{2}$ equal parts from any scale, will give the angle p (or P) $\approx 56\frac{1}{4}^\circ$ nearly.

70. *Through a given point P , to draw a line CD parallel to a given line AB .*

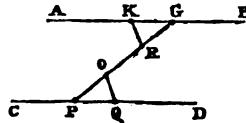
From P draw PG in any direction to meet the given line AB ; then make the angle GPD equal to the angle



AGP (65°); and PD will be parallel to AB : because the alternate angles AGP , GPD , are equal.

71. *To trace the parallel CD on the ground.*

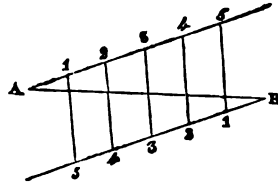
Fix on any convenient point G in AB , and measure an isosceles triangle $R GK$; then, at the point P , lay down



the triangle OPQ equal to $R GK$; and PQ will be parallel to GK .

72. *To divide a given line AB into a proposed number of equal parts—suppose five.*

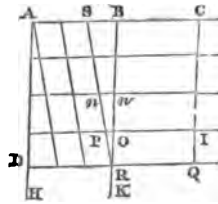
From the extremities A and B , draw two lines, parallel to each other, forming any convenient angle with AB : on these lines, set off five equal parts of any length; join the



opposite points of division ; and AB will be divided into five equal parts.

73. Diagonal scales, which are constantly used, are thus constructed. Suppose a scale to 12ths of a line AB is required.

Having divided AB into three equal parts, draw two parallel lines AH , BK , making any convenient angle with AB : on these lines, take four equal distances—suppose from A to D and from B to R ; and through the



points of division draw four lines, parallel to AB ; next, divide DR into three equal parts; then, if the points of division in AB and DR are joined diagonally, the scale is constructed.

For by similar triangles, $RB : BS :: RO : OP$; therefore, RO being $\frac{1}{3}$ of RB , OP will be $\frac{1}{3}$ of BS , or $\frac{1}{3}$ of $\frac{1}{3}$ (or $\frac{1}{12}$) of BA ; and the next division nn is $\frac{2}{12}$, &c.

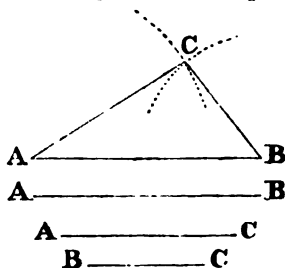
If $QR = CB = BA$ is the scale of a *foot*, OP is an *inch*, $nn = 2$ inches, $IP = 13$ inches, &c. But if we divide AB into 4 equal parts, only 3 must be taken on AH and BK , to make 12ths of AB (because $4 \times 3 = 12$).

Generally, resolve the number to which the divisions are to be extended, into two factors, then divide the given

line (A B) into as many equal parts as there are units in one factor, and take as many equal parts on the other lines (A H, B K) as there are units in the other. Thus, if A B is divided into 3 equal parts, and 5 are taken on A H, B K, or if A B is divided into 5, and 3 are taken on A H, B H, in either case the scale gives 15ths of A B. On the common plain scales with mathematical instruments, the equal parts on each line are 10, which give the divisions in 100ths.

74. *Three lines A B, A C, and B C, being given, to form a triangle with them.*

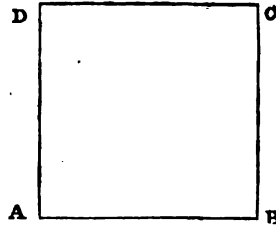
First, draw a line, and measure upon it the length of A B. Next, take the length of A C in the compasses (or on a piece of cord if the operation be performed on the ground), and with one leg at A, sweep a short curve with



the other leg. Then take the length of B C in the compasses, and with one leg at B, sweep a curve that will cut the one previously made from A. Lastly, join the point C (where the curves cross) to A and B, and the triangle is completed.

75. *To construct a square, whose side shall be equal to a given right line.*

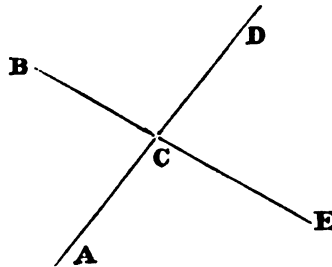
Let the given line A B = 4 chains. Erect a perpendicular at B, which make equal to A B, then on A and B



as centres, and with a radius equal to AB , describe arcs cutting each other in D . Draw the lines AD and CD , and the square is completed.

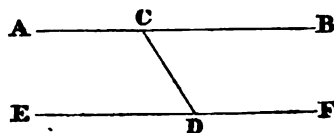
76. *If one straight line cuts or crosses another, the opposite angles are equal.*

Thus, the angle BCA is equal to the angle DCE , and the angle BCD is equal to ACE .



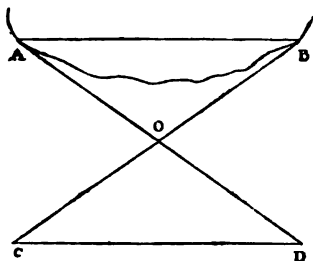
77. *If a straight line be drawn so as to join two parallel lines, the alternate angles will be equal.*

Thus AB and EF being parallel, the angle BCD is equal to the angle EDC , and the angle ACD to FDC .



78. *To find the length of the line AB accessible only at both ends.*

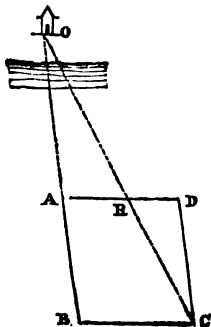
Having fixed on some convenient point O, measure BO and AO; and prolong those lines till $OC = OB$, and $OD = OA$; then the distance between the points D and C, will be equal to AB.



For the sides of the triangles COD, BOA about the equal angles at O are respectively equal, therefore the third sides CD, BA will also be equal.

79. *To find the distance of an inaccessible object, O, by means of a rhombus.*

With a line or measuring tape, whose length is equal to the side of the intended rhombus, lay down one side BA



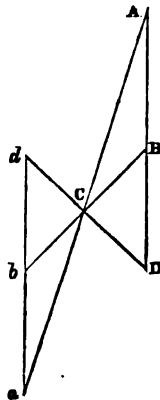
in the direction BO , and let BC another side be in any convenient direction: fasten two ends of two of those lines at C and A ; then the other ends (at D) being kept together, and the lines stretched on the ground, those lines AD , CD , will form the other two sides of the rhombus. Set up a mark at R , where OC , AD , intersect; and measure RD ; then the sides of the triangles ADC , CBO , being respectively parallel, the triangles will be similar; hence, $RD : DC :: CB : BO$.

Suppose the side of the rhombus is 100 feet, and $RD = 11\text{-ft. } 7\text{-in.}$, then $11\frac{7}{12} : 100 :: 100 : 863\text{ feet nearly} = BO$.

If the ground be nearly level, a rhombus, whose side is 100 feet, will determine distances to the extent of 300 yards within a very few feet of the truth.

80. *Another method of finding the distance to any inaccessible point, without an instrument for measuring angles.*

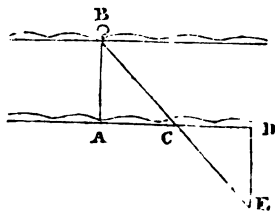
A is an inaccessible point, whose distance from B is required. Produce AB to any point, D , draw Dd , in any



direction, and find C , the point bisecting it; join BC , and produce it to b , Cb being equal to BC ; join db , and produce that line to a , meeting AC prolonged; then $ab = AB$, and $ad = AD$.

81. *To find the breadth of a river.*

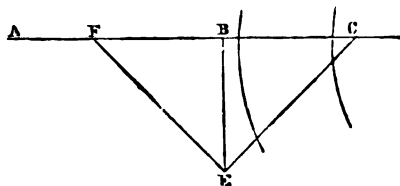
Fix upon any object, B , on the margin of the river on the opposite side. By means of an instrument, make AD perpendicular to AB . Take AC , of any convenient length,



and make CD equal to AC ; erect the perpendicular, DE , and fix a mark at E , in line with BC ; then will DE be equal to AB , the breadth of the river.

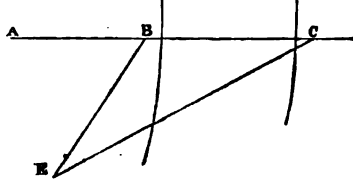
82. *Another method.*

On a line, AB , take a point, F , making FB greater than the breadth of the river; set up a mark at E , forming a



right angle at the point B , and make BE about equal to FB : then, with any instrument for taking angles, make the angle, BEC , equal to BEF . Place a mark at C , in line with AB , and BC will be equal to FB .

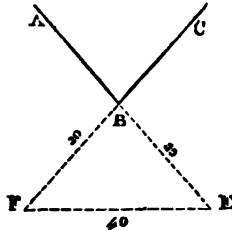
83. Or, make BE to form any convenient angle with AB , and make the angle BEC , equal to half the angle,



ABE ; then, a mark being set up at C , in the prolongation of AB , BC will be equal to BE .

84. *To measure from the outside an angle, ABC , formed by two walls, AB , CB .*

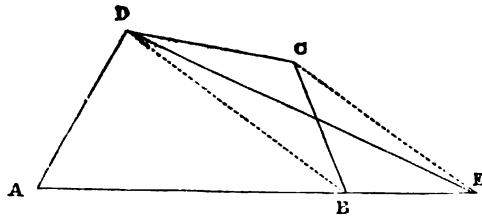
Lay off 30 feet from B to E in the direction AB , and plant a staff at E ; set off the same measure from B to F



in the direction BC , and measure FE , and you may obtain the measure of your angle, either by laying it down on paper, or by calculation.

85. *To reduce a given trapezium, $ABCD$, to a triangle of equal area.*

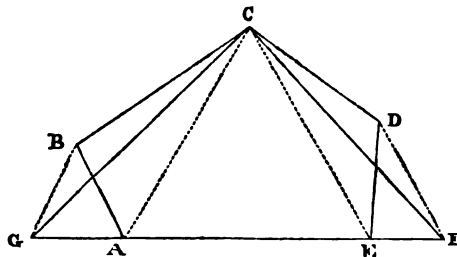
Draw the diagonal DB , and parallel to it draw CE , meeting AB produced in E . Join the points DE ; so shall the triangle ADE be equal to the trapezium $ABCD$:



for the triangle DBE is equal to the triangle DCB, having the same base and altitude.

86. *To reduce an irregular polygon, ABCDE, of five sides, to a triangle of equal area.*

Extend the side AE, both ways at pleasure; and draw the diagonals CE, CA. Parallel to these diagonals draw



the lines DF and BG; join the points CF, CG; and GCF will be the triangle required.

Note. — This and the former problem may be applied in finding the areas of trapeziums and irregular polygons, by first reducing them to triangles.

I think the learner should endeavour to make himself master of the Definitions and Problems, which I have selected as the most useful; but as some few of them may be found difficult to understand by a pupil who is wholly ignorant of geometry, I recommend an instructor not to be too rigid in insisting on their being mastered before he proceeds with his pupils to the field.

A DESCRIPTION OF THE COMMON INSTRUMENTS USED
BY LAND SURVEYORS.

THE CHAIN.

87. Land is commonly measured with a chain, invented by Mr. Gunter, which is known by the name of "*Gunter's Chain*."

It is 4 poles, 22 yards, or 66 feet, in length, and divided into 100 equal parts, called links; each link being 7·92 inches. At every tenth link from each end, is fixed a piece of brass, with notches or points; that at 10 links having one notch or point; at 20, two; at 30, three; and at 40, four points. At 50, or the middle of the chain, is a round piece of brass. Part of the first link, at each end, is made into a handle.

In folding up the chain, it is most expeditious to begin at the middle, and fold it up double. When you wish to unfold it, take both the handles in your left hand, and the other part of the chain in your right; then throw it from you, taking care to hold the handles fast. Chains which have three rings between each link, are better than those which have only two, as they are not so apt to twist.

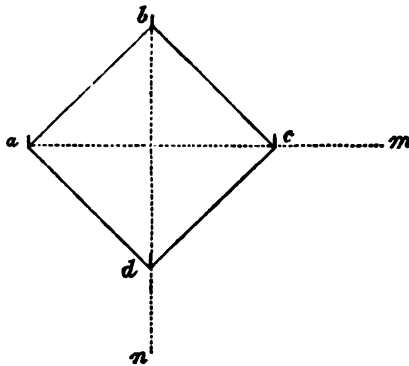
THE CROSS-STAFF.

88. The cross-staff is a very simple instrument, used for the purpose of erecting perpendiculars, which are constantly required by a surveyor. It may easily be made in the following manner.

Procure a piece of board about six inches square, and draw on it, with great accuracy, the two diagonals; fixing

at each corner, and on the diagonal, a small stud or pin. Fix the board upon a staff, of any convenient length for use, which should be pointed with iron, that it may easily be pressed into the ground.

The cross must be fixed upon the staff by a screw, in such a manner that it may readily be turned round without moving the staff. Suppose $abcd$ to represent a cross,



then if, by looking along the line ac , that is keeping the pins at a and c in one, we see an object at m , the line bd will point in the direction of n , at right angles to the line acm .

Any one may make such a cross-staff for himself, and with sufficient accuracy; but a far superior instrument for the same purpose, and small enough to be carried in the waistcoat-pocket, called the "Optical Square," will be described further on in a more appropriate place.

THE OFF-SET STAFF.

89. Short distances to the right or left of a line we are measuring with a chain, termed off-sets, are usually measured with a rod, called an off-set staff, which may be 10, 12, or 15 links long.

A measuring-tape is very useful for taking off-sets, or making any short measurements: it may be of the same length as Gunter's chain, viz., 66 feet; one side of it being divided into feet and inches, the other into links. The tape winds up into a leathern box, about four inches in diameter.

THE FIELD-BOOK.—MARQUËS SCALES AND TRIANGLE.—
PLOTING SCALE. — MATHEMATICAL INSTRUMENTS. —
OF SCALES.

THE FIELD-BOOK.

90. Surveyors use what is called a field-book, for keeping a register of all measurements and observations made in the field; which is a common memorandum-book divided into three columns, by drawing two lines lengthwise along each page, so as to leave the middle column about three quarters of an inch wide. This middle space may be called the chain column, as in it are set down the distances along the line you are measuring, at which an off-set is taken or any observation made; while the space to the right and left of the middle column, contains the distances to which the off-sets extend, and also notes of any observations that may be made.

All measurements taken to the right or left of the chain-line to determine the distance and *position* of a house, a gate, a fence, &c., &c., are usually made at right angles to such chain-line: if the distance be short—say not exceeding 30 or 40 links—the eye, when the chain is drawn tight, may fix the point where a perpendicular would fall; but for greater distances, a cross-staff, or some other instrument for forming a right angle, should be used. Off-sets may

be measured by means of a measuring tape, or when the distances are short, with a staff for that purpose, called an off-set staff.

It is the universal practice to begin at the bottom of each page in the field-book, and write upwards, for the convenience of plotting or laying down a plan of the survey; and it will materially assist the plotting, if all fences, roads, or other lines, across which you measure, be marked in the field-book by short lines drawn opposite the figures in the middle column, showing nearly the angles which the fences, &c., make with the chain-line; the corners of fields also, and bends in the fences to which off-sets are made, should be shown in the field-book. *See the Field-book and Plan in the 1st plate, which have been formed with great care upon the principles above recommended.*

The points from which measurements begin are called *stations*, and this mark ($\odot$), both in the field-book and on the plan, denotes a station.

Some surveyors use the signs $\lceil$, $\lceil$, (to the right, to the left) in their field-book; signifying that, after having measured to a station, you must turn to the right or left when proceeding towards the next station: others put it thus, R from $\odot$ A, L from $\odot$ A. Without some direction entered in the field-book, it would be impossible to lay down a survey made with the chain; for you would be as likely to construct a triangle on the wrong, as on the right side of a main line.

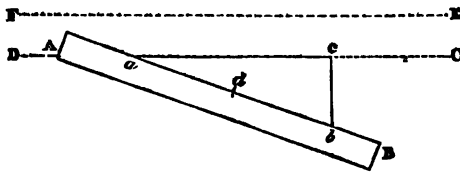
USE OF MARQUOIS SCALES AND TRIANGLE.

91. The methods of raising and letting fall perpendiculars, forming right angles, drawing parallel lines, &c., as shown in the geometrical problems, are only employed by practical men when their plans are upon a very large

scale: they commonly use a flat ruler and triangle, by which perpendiculars are formed, and parallel lines drawn, much quicker, and even more accurately.

Many years ago the late Mr. Marquois devised the scales of equal parts to which his name has been attached, which are always accompanied by a triangular ruler. The following brief description will assist the learner in acquiring the use of the scales, with which the students at our military colleges are all familiar.

The triangle is right-angled, and its hypotenuse, or longest side ab (see diagram), is exactly three times the length of the shortest, or perpendicular bc .



The method of drawing parallel lines by means of one scale, or ruler, and the triangle, is thus:—

Suppose that a line is to be drawn through a point F, parallel to another line DC; place the triangle so that its edge ac shall agree with the line DC; then apply the ruler AB to the opposite, or hypotenuse side ab ; press it down with the left hand to keep it steady, while with the right you slide the triangle towards A, until the edge ac touches the point F; draw a line along this edge and you obtain the parallel line FE.

But besides drawing parallel lines, we can draw them at given distances, and more accurately than by measuring off the distances with a pair of compasses. Each edge of the rulers is graduated, and marked from the middle, 10, 20, 30, &c., both ways; and below this graduation is another scale which is numbered from left to right, the left division being divided into 10 equal parts, while the

others are numbered 1, 2, 3, 4, &c., to a considerable length. Under this second scale, and at the centre, is the number 20, or 25, 30, 35, 40, 45, 50, or 60; which signifies, that so many of the minute divisions at the left hand of the lower or inward scale go to an inch. For instance, take the scale of 20, the 1st division on the left contains 10 equal parts, and two of them therefore contain 20 of those parts, the measure of which is an inch.

For the sake of distinction, the outer scale, or that at the edge, is termed the *artificial* scale; and the inner, or second, the *natural* scale. The artificial is just three times the size of the natural scale, that is, three of the small divisions of the latter make one of the former. Now, the triangular ruler above mentioned has its longest side, precisely three times the length of the shortest side; therefore, the artificial and natural scales on the rulers are in the same proportion to each other as the longest and shortest sides of the triangle, viz. 3 to 1. In practice, suppose you are working by the scale of 20, and that you call each of the smallest divisions 10 links, the largest divisions will be then 100 links, and you are using a scale of 200 links to an inch. Again, suppose you wish to draw a line parallel to another in your plan at 10 links distance; to do this, you have only to adjust the thin edge of the triangle to the line, apply your scale of 20, so that the zero line, or centre, agree with the index *d* of the triangle (see diagram), and slide the triangle one division, as denoted by the index; when, if a line be drawn along the triangular ruler, it will be just 10 links, or the 20th of an inch from the former line. For 100 links, slide 10 divisions of the outer scale, and so for any number.

If you are using the outer scale without reference to the inner one, and want to draw parallel lines at given distances, you have only to slide 3 divisions for the distance

of one of them measured perpendicularly. Referring to the scale marked 30, 10 of the outer divisions go to an inch, and therefore to draw parallel lines an inch apart, slide 30 divisions. It may be of use to remember, that on the scale marked 60, 10 of the outer divisions make half an inch.

Suppose you wish to draw a line parallel to another at a great distance, upon paper. Place the two rulers side by side, causing the edge of one of them to agree with the given line, you may then move them alternately, advancing them towards the part of your paper at which the intended parallel line is to be drawn, taking care to keep one always firmly pressed down while moving the other. Or, you may lay one of the rulers on the paper and place the short side of the triangle against it, when it is evident that you may draw parallel lines by sliding the triangle up or down.

Lastly, the ruler and triangle are exceedingly useful when a perpendicular straight line is required to be drawn. For instance, if a line be drawn along the edge cb (see diagram), it will be at right angles to DC ; and by sliding the triangle to the left or right, all lines drawn along the edge cb will be equally perpendicular to DC . As the student will constantly want to draw perpendiculars in this way, when constructing the figures of fields, and laying down off-sets, I recommend him to procure a pair of Marquois scales with the triangle, and to make himself master of the methods of using them.

THE PLOTTING SCALE.

92. Surveyors generally use what is called a plotting scale for measuring off-sets: this is an ivory ruler about 6 inches long, the edges of which are graduated from the centre; and by making a line which crosses the scale to

agree with the chain line, the length of each off-set can then be marked off at once. This instrument need not be described here, as learners seldom use it.

OF MATHEMATICAL INSTRUMENTS.

93. Surveys cannot be laid down, nor indeed can any figures be accurately constructed, without the aid of a pair of compasses and a scale of equal parts; but these two instruments, with a black-lead pencil, are all that are absolutely necessary. However, as plans ought to be neatly executed, a steel line-drawing pen is wanted; and it is convenient also to have the means of fixing a pencil-leg to the compasses for sweeping arcs of circles, &c. We will then allow the student to require,—

1st. A pair of compasses.

2nd. A steel drawing-pen, to fix into a leg of the compasses.

3rd. A pencil-leg to do the same.

4th. An ivory “plain-scale,” having engraved upon it two diagonal scales, viz., half and quarter inch, with other scales on the reverse side, while its edges are graduated from 0 to 180 degrees, for laying-off angles.*

* The above are all the instruments really required by a young student in common surveying; and having applied to Messrs. THOUGHTON and SIMMS, the eminent opticians of 136, Fleet-street, they inform me, that a set of such instruments, in a case, could be furnished for 12s.; but they recommend that the price should be 14s., in order to have them of good quality.

An ordinary case of instruments contains the following:—

1. Large Compasses.
2. Small Ditto.
3. A Drawing-Pen.
4. Bow-Compasses.

OF SCALES.

94. The divisions used for measuring straight lines, are called *scales of equal parts*, and are of various lengths, for the convenience of delineating any figure of a large or smaller size, according to the fancy or purposes of the draughtsman. They are, indeed, nothing more than a measure in miniature, for laying down, upon paper, any known measure, as chains, yards, feet, &c., each part on the scale answering to one link, one foot, one yard, &c.; and the plan will be larger or smaller, as the scale contains a smaller or greater number of parts in an inch. Hence a variety of scales is useful to lay down lines of any required length, and of a convenient proportion, with reference to the size of the plan.

Scales, of equal parts, are divided into two kinds; the one simply, the other diagonally divided.

Six of the simply divided scales are often placed one above another upon the same ruler; they are each divided into as many equal parts as the length of the ruler will admit of; the number attached to each indicates how many parts to an inch the scale is divided into.

The diagonal scale enables us to take off measurements with the utmost accuracy; for any one of the larger divisions (which are half an inch long on a 6-inch ivory ruler, con-

-
- 5. Steel Pen, to fit large Compasses.
 - 6. Pencil-Leg, for ditto.
 - 7. Pencil-Holder.
 - 8. Ivory Plain-Scale.
 - 9. Parallel Ruler.
 - 10. Sector.

Of these, it is sometimes convenient to have the second size compasses (2), and the drawing-pen (3), in addition to what I have recommended above; but neither bow-compasses (4), nor the pencil-holder (7), are wanted. The parallel ruler is a useless toy, and nobody uses the sector.

tained in a set of mathematical instruments,) may be subdivided into 100 equal parts; and therefore, if the scale contain 10 of the larger divisions, any number from 1000 downwards may be taken off with perfect accuracy.

The 6-inch ivory ruler has now always two diagonal scales upon it, namely, the half and quarter inch scales, and the first division of each is subdivided into 10 equal parts: hence, if a large division be taken as 100, the small divisions will be each 10; and the units are obtained by means of eleven parallel lines, making 10 divisions upwards (for the principle of the construction of a diagonal scale, see 73).

Let the learner consider well the construction of a diagonal scale, and then try to take off numbers from it.

Example 1. — To take off 344. Set one point of the compasses on the place where the third vertical line cuts the fourth horizontal one, and extend the other point to where the fourth diagonal cuts the fourth horizontal line.

Example 2. — To take off 523. Set one point of the compasses on the spot where the fifth vertical cuts the third horizontal line, and extend the other point of the compasses to where the second diagonal cuts the third horizontal line.

Example 3. — To take off 2 chains 22 links. Set one point of the compass on the place where the second vertical cuts the second horizontal line, and extend the other point to where the second diagonal cuts the second horizontal line.

TO MEASURE A LINE ON THE GROUND.

95. If the line be short, a *measuring-tape*, which is either divided into *feet* and *inches*, or *links*, may be used; but for long lines, *Gunter's chain* (87) is the measure universally adopted in this kingdom for land surveying.

Directions for using the chain.—Marks are first to be set up at each end of the line which is to be measured; the place where you begin may be called the first station; and the station to which you measure, the second station. Two persons are to hold the chain, one at each end; and the foremost, or chain-leader, must be provided with ten arrows, or pins of stout iron wire. The chain leader draws the chain forward, until the *follower* calls Stop; he then turns round and faces the latter, both standing upright, and holding the chain with both hands; the *follower* then motions the leader, by hand, to move right or left, until he is exactly in line with the mark to which they are measuring; when both stoop down, draw the chain tight, and the leader places an arrow at the end of the handle of the chain, which being afterwards taken up by the follower, an account is kept of the number of chains measured. At the end of 10 chains, the leader will have expended all his arrows, which have become transferred to the follower. When the eleventh chain is measured, the latter runs forward, and restores the 10 arrows to the leader, who should count them to see that he has 10, and then place one to mark the eleventh chain.

In order to keep an account of the number of times which the arrows are thus exchanged, they should each tie a knot on a string, carried for that purpose, and which may be fastened to a button or button-hole of the coat; they should also call out the number of those exchanges, that the person directing the measurement may have a check upon them.

SECTION II.

MENSURATION OF PLANE FIGURES—METHODS OF SURVEYING FIELDS, OR PORTIONS OF GROUND OF VARIOUS FORM, AND COMPUTING THEIR CONTENTS OR AREAS.

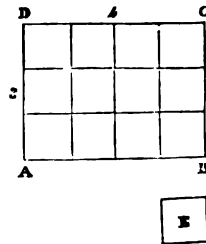
THE pupils are supposed to have had some field practice in a few of the foregoing problems, and that they can use the chain, and readily describe figures on the ground. They may now be shown how to survey fields, and portions of ground, computing at the same time their areas; but to find areas, a slight knowledge of the theory of square measure is necessary.

MENSURATION OF PLANES.

96. The area of any plane figure is the measure of the space contained within its lines or bounds.

This area or content is estimated by the number of squares that may be contained in a figure; the length and breadth of those squares being an inch, a foot, a yard, an acre, or any other fixed quantity. And hence the area or content is said to be so many square inches, or square feet, or square yards, &c.

Thus, if the figure to be measured be the four-sided one, $A B C D$, which is termed a rectangle (its four angles being



right angles), and the little square E, whose side is one inch, be the measuring unit proposed: then, whatever number of those little squares may be made to fit into the figure, so many square inches it is said to contain; which in the present case is 12.

TABLE OF SQUARE MEASURE.

144 Square Inches	make	1 Square Foot	. .	<i>Ft.</i>
9 Square Feet		1 Square Yard	. .	<i>Yd.</i>
30 $\frac{1}{2}$ Square Yards	. . .	1 Square Pole	. .	<i>Pole.</i>
40 Square Poles		1 Rood		<i>Rd.</i>
4 Roods		1 Acre		<i>Acr.</i>

<i>Sq. In.</i>		<i>Sq. Ft.</i>								
144	=	1	=	<i>Sq. Yd.</i>						
1296	=	9	=	1	<i>Sq. Pole.</i>					
39204	=	272 $\frac{1}{2}$	=	30 $\frac{1}{2}$	=	1	<i>Rd.</i>			
1568160	=	10890	=	1210	=	40	=	1	<i>Acr.</i>	
6272640	=	43560	=	4840	=	160	=	4	=	1

627264 Sq. Inches	=	1 Sq. Link.
625 Sq. Links	=	1 Sq. Pole or Perch.
10,000 Sq. Links	=	1 Sq. Chain.
25,000 Sq. Links	=	1 Sq. Rood.
10 Sq. Chains	=	1 Sq. Acre.
100,000 Sq. Links	=	1 Sq. Acre.

A *pole*, *perch*, and *rod*, are the same measure.

Now the rule for finding the area of a rectangle is to multiply the length of the base by the height. In the figure above, this base is called 4 inches, and perpendicular 3 inches; and $3 \times 4 = 12$ square inches.

97. *To find the area of any parallelogram, whether it be a square, a rectangle, a rhombus, or a rhomboid.*

Multiply the length, stated in any linear measurement, as inches, feet, yards, &c., by the perpendicular height, and the product will be the area.

*Example:—*To find the area of a parallelogram, whose length is 12·25 feet, and breadth or height 8·5 feet.

$$\begin{array}{r}
 12\cdot25 \text{ length.} \\
 8\cdot5 \text{ breadth.} \\
 \hline
 6125 \\
 9800 \\
 \hline
 104\cdot125 \text{ area.}
 \end{array}$$

We shall now proceed to the practice of mensuration, by showing how fields, of various form, may be surveyed by the chain and cross-staff.

Gunter's chain is, as before stated, 4 poles, or 22 yards, or 66 feet, in length; and is divided into 100 links; each link is, therefore, $\frac{3}{100}$ of a yard, or $\frac{6}{100}$ of a foot, or 7·92 inches.

98. Land is estimated in acres, roods, and perches. An acre is equal to 10 square chains, or as much as 10 chains in length, and 1 chain in breadth. Or, in yards, it is $220 \times 22 = 4840$ square yards. Or, in poles, it is $40 \times 4 = 160$ square poles. Or, in links, it is $1000 \times 100 = 100,000$ square links: these being all the same quantity.

Also, an acre is divided into 4 parts, called roods, and a rood into 40 parts, called perches, which are square poles—or the square of a pole of $5\frac{1}{2}$ yards long—or the square of $\frac{1}{4}$ of a chain—or of 25 links, which is 625 square links. So that the divisions of land measure will be thus:—

625 square links = 1 pole or perch.
 40 perches . . . = 1 rood.
 4 roods = 1 acre.

The lengths of lines, measured with a chain, are best set down in links as integers, every chain in length being 100 links; and not in chains and decimals. Therefore, after the content is found, it will be in square links; then cut off five of the figures on the right hand for decimals, and the rest will be acres. These decimals are then multiplied by 4 for roods, cutting off five figures as before, and the decimals of these again by 40 for perches, when five figures are again to be cut off.

EXAMPLE.

99. Suppose the length of a rectangular piece of ground be 792 links, and its breadth 385; to find the area in acres, roods, and perches.

792	3·04920
385	4
3960	·19680
6336	40
2376	
	7·87200
3·04920	

Ans. 3 acres, 0 roods, 7 perches.

TO MEASURE A TRIANGULAR FIELD.

100. To measure or survey a triangular field, a mark—such as a pole or a stick, with a bit of white paper on it—must be set up at each corner; then with the chain measure on the longest side, keeping, of course, in a direct line between its two marks, until you arrive near

the place where a perpendicular from the opposite angle would fall upon the line you are measuring. Here set up your cross-staff, which must be turned until the pins, or sights of one diagonal of the instrument, agree with the mark at each end of your base line, as it may be termed,—to be judged of by placing the eye alternately on each side of the instrument. Then look along the other diagonal of the cross-staff, to see whether its sights are in line with the opposite angle of the triangle. Should they be so, your instrument stands at the right point from which to measure the perpendicular: but it generally requires two or three moves before the right place is determined, during which you must be careful not to deviate from your base line.

You then use your chain, to measure the perpendicular, being careful to note in your field-book the distance along the base line at which it falls, together with its length. After which, continue the measurement of the base line up to the mark.

To lay down the triangle upon paper.

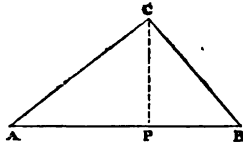
101. Draw a line, and then take from any convenient scale of equal parts the number of chains and links corresponding with the measurement of your base line: set off its length, whatever that may be, and also the distance along it from whence the perpendicular was measured; with your ruler and triangle (91), draw a line from the proper point, forming a right angle with the base line, and upon it, from the same scale of equal parts, set off the length of the perpendicular; from the end of which lines are then drawn to the extremities of the base.

Rule, for finding the area or superficial measurement of a triangle.—Multiply the length of the base by the perpendicular, and half the product is the area.

EXAMPLES.

102. It is required to survey and compute the area of a triangular field, A B C.

Having placed a mark at each corner, measure from A towards B, and when you come near to the point where a perpendicular, C P, from the angle at C, would fall upon the line A B, set up the cross-staff, and try for the per-



pendicular, as above directed: then, having found the point P, measure the line P C; after which continue the measurement of A B.

We will suppose A P to be 568 links,
 P C 444 ,,
 A B 940 ,,

The following is a good method of entering the measurements in your field-book.*

	A B	Base line.
	940	
C 444	568	P
Began	at A	

Construction.

Draw a straight line, and along it lay off 940 from any scale of equal parts,—the distance, A B, of the base line,—and mark one end as $\odot$ A, the other $\odot$ B; then take from the same scale 568, the distance along A B, at which the

* The learner will remember that all field-book notes begin at the bottom.—(See 90.)

perpendicular, CP, falls, and mark the point P; here raise a perpendicular, by problem 52, or draw one by means of a ruler and triangle (91), and with 444 in your compasses set off the distance of C from P. You have now the three points of a triangle, and have only to join C with A and B, to complete it.

Calculation for the area.

$$\begin{array}{r}
 940 \text{ Base.} \\
 444 \text{ Perpendicular.} \\
 \hline
 3760 \\
 3760 \\
 3760 \\
 \hline
 2) 417360 \text{ Double area.} \\
 \hline
 208680 \text{ Area in links.} \\
 4 \\
 \hline
 \cdot 34720 \\
 40 \\
 \hline
 1388800
 \end{array}$$

The area, reduced to acres, roods, and perches, is 2 A. 0 R. 13 $\frac{3}{4}$ P. nearly.

103. Let the learner construct a figure, and find its area from the following field notes. He will observe that the perpendicular is taken to the right of the base line, whereas by referring to the field notes of the last example, he will find that it was in that case taken to the left.

A B	256 D perpendicular.
964	
C 430	
Began at B	

Ans. 1 A. 0 R. 37 $\frac{1}{4}$ P. nearly.

104. Measuring upon the longest side of a triangular field, I found the perpendicular at 1400 links; the perpendicular measured 880, and the whole base 2800 links. How many acres, &c. did the field contain?

Ans. 12 A. 1 R. 11 P.

105. The base A B of a triangular field measured 1900 links, the perpendicular lay to the left hand when going from A towards B; the distance from A to a point D where the perpendicular C D fell, was 760, and the length of the perpendicular was 862. Required, a plan of the field and its area?

Ans. 8 A. 0 R. 30 P.

106. *To survey a four-sided figure.*

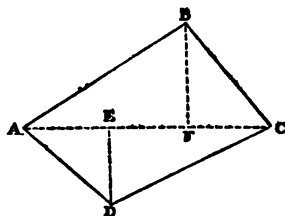
When surveyors have to compute the area of any quantity of land, they generally find that the most convenient way of doing so, is to divide it into triangles and trapeziums, the areas of those figures being very soon calculated. The best way of finding the area of a trapezium is to divide it into two triangles by a diagonal, which diagonal is a base common to both; having the length of which, and the lengths of the perpendiculars of both triangles, the area of the trapezium is found by the following

Rule.—Add the lengths of the two perpendiculars together, multiply their sum by the length of the diagonal, divide this product by 2, and the quotient will be the area.

EXAMPLE.

107. A plan and the area of the trapezium A B C D is required.

Divide the figure into two triangles by the diagonal A C, then measure from A towards C, find the distances from



A at which the perpendiculars ED and BF fall upon the line AC, measure those perpendiculars, and afterwards complete the measurement of AC. The following are the field-book notes measured in links.*

	A C	Diagonal.
	1010	
B 430	670	F
E	340	325 D
Began at	A	

Construction.

Draw a line, and upon it lay off the length of the diagonal AC, 1010, taken from a scale of equal parts, and place the letters A and C. Set off 340, the distance AE, draw a line from E on the proper side of AC, at right angles to AC, and let D be 325 from E. Next, take the distance to F 670, and make the perpendicular FB = 430; join the points B and D with A and C, and the figure is formed.

Calculation.

$$\begin{array}{rcl}
 325 & \} & \text{Perpendiculars.} \\
 430 & \} & \\
 \hline
 755 & \text{Sum.} &
 \end{array}$$

* To prove your work, measure in the field the diagonal BD, and after having constructed your plan, take the length BD from it, and see whether its length when applied to the scale agrees with the measured distance.

$$\begin{array}{r}
 755 \text{ Sum.} \\
 1010 \\
 \hline
 7550 \\
 755 \\
 \hline
 2) 762550 \text{ Double area of figure in links.} \\
 381275 \\
 4 \\
 \hline
 325100 \\
 40 \\
 \hline
 1004000
 \end{array}$$

Ans. 3 A. 3 R. 10 P.

108. Required, the plan and content of a quadrilateral field from the following notes :—

	A B	Diagonal.
	1945	
E 784	1690	F
D	425	654 C
Began	at A	

Ans. Area = 13 A. 3 R. 37 P.

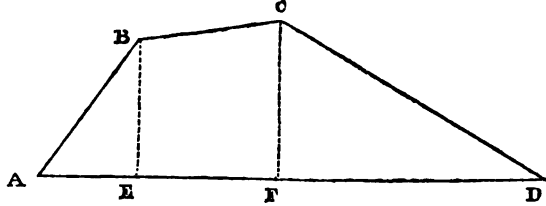
109. Required, the plan and area of a field from the following notes :—

	A B	Diagonal.
	3400	
	1974	642 E
C 276	430	D
Began	at B	

Ans. 15 A. 2 R. 17 P. nearly.

110. A trapezium may be surveyed by dividing it into two triangles and a trapezoid. The following figure is

divided into two triangles ABE, CDF, and a trapezoid EBCF.



Required, the plan and area of a quadrilateral field by the above method, from the following notes :—

	A D	Base.
	1642	
E	1322	445 B
F	889	523 C
Began	at D	

Before entering on the calculation, let it be remembered that a trapezoid is a figure of four sides, two of which are parallel lines.

Rule to find the area of a trapezoid.—Add the two parallel sides together, multiply their sum by the perpendicular distance between them, and half this product is the area.

Calculation.

Triangle A B E	Triangle C D F
445 Per.	889 Base.
320 Base.	523 Per.
8900	2667
1335	1778
142400 Double area.	4445
	464947 Double area.

Trapezoid E B C F	142400	} Double areas collected.
523 C F	464947	
445 E B	419144	
968 Sum.	2)1026491	
433 E F	5·13245	
2904	4	
2904	·52980	
3872	40	
419144 Double area.	21·19200	

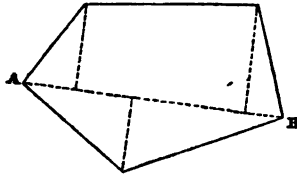
Area of whole figure, 5 A. 0 R. 21 P.

Note. — The figure to 110, and all that follow as far as 124, are accurately drawn to a scale of 6 chains to an inch: the learner may therefore apply his compasses when in doubt respecting the length of any lines in the examples.

111. *To survey figures bounded by more than four straight lines.*

The best method of surveying ground bounded by any number of straight lines, is to divide it into triangles and trapeziums.

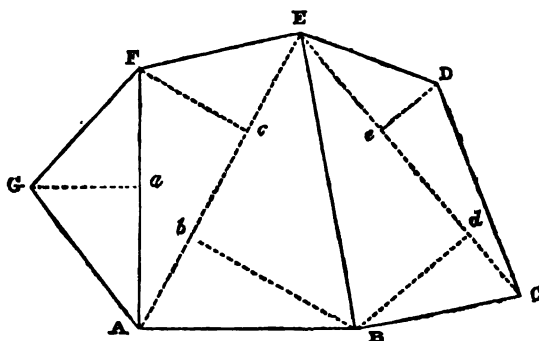
Thus, a field of 5 sides, as below, may be divided into a triangle and a trapezium; one of 6 sides into two trapeziums; of 7, into two trapeziums and a triangle, and so on.



The area of a piece of ground thus subdivided is obtained, by finding the double area of each triangle and trapezium separately in links, then adding all the double

areas together, dividing the sum by 2, and lastly, reducing the area in links to acres, roods, &c., in the manner already shown.

112. The seven sided figure below is divided into a triangle, A G F, and two trapeziums, A B E F and B C D E.



Field-notes to the above figure.

	BC	
	520	
L. from	B	
	EC	Diag.
	1112	
<i>d</i>	857	450 B
D 250	423	<i>e</i>
R from	E	
	AF	Base.
	814	
G 355	436	<i>a</i>
Return to	A	
	AE	Diag.
	1062	
F 385	723	<i>c</i>
<i>b</i>	307	610 B
Began at	A	

Construction.

Draw a line, and at one end of it mark a point, A. From A, set off 307, and raise a perpendicular, 610 long, to the right, which fixes B. Again, from A, lay off 723, and make the perpendicular to the left 385, which determines the point F. The whole length, A E, is 1062, forming the diagonal of a trapezium, A B E F.

Next for the triangle A F G. Along A F, take 436, and a perpendicular to the left of 355 fixes G.

Lastly, for the trapezium B C D E. We have the line B E laid down, and we have also the length of the diagonal E C, together with B C; we can therefore construct a triangle, E B C. Along E C lay off from E 423, make the perpendicular on the left 250, to determine D, and the figure is completed.

The area is 10 A. 2 R. 19 P.

113. Required the plan and area of a field, from the following notes :—

	A C	Diag.
	1295	
B 471	862	
	465	328 D
Began	at A	

	DC	
	892	
	564	475 F
Went	to D	
	BA	
	973	
	442	236 E
Went	to B	

Construction.

A little consideration shows us, that we have here the measurements of three figures, viz. (beginning at the bottom) a four sided figure (trapezium) and two triangles.

First draw a line, upon which take 1295 from a scale of equal parts, and call the line A C. Next, from A, lay off 465 along the line A C; erect a perpendicular on the right, and lay off upon it 328, which fixes the point D.

Again, from A, lay off 862, along A C; erect a perpendicular 471 in length, to fix B. Draw lines from A and C to B and D, and the trapezium A B C D is completed.

Now, from B lay off along the line B A, 442; raise a perpendicular, 236 in length, which fixes E. Join E B and E A, to complete the triangle A E B.

From D lay off 564 along D C, raise a perpendicular 475 in length, to fix the point F; join F to D and C, which will complete the triangle D F C.

Trapezium, A B C D	1034705	} Double areas collected.
Triangle, A E B . .	229628	
Triangle, D F C . .	423700	

2) 1688033

2) 1688033

8·44016

4

1·76064

40

28·42560 Area = 8 A. 1 R. 28½ P.

114. Required the plan and area of a field, from the following notes :—

Went	BA	184 E
	800	
	320	
	to C	
C 240	AD	Diag.
	1032	
	855	
	426	
Began	at A	375 B

Ans. 3 A. 3 R. 25½ P.

115. A field, consisting of many sides, is often most conveniently surveyed, by measuring one diagonal, and erecting perpendiculars from it to all the angles on each side. The figure then becomes divided into right-angled triangles and trapezoids, the double areas of each of which must be found, and their sum reduced as before.

116. Make a plan, and compute the area of a figure by the following notes:—

	A K	
	2040	Diag.
H 264	1432	I
F	1012	260 G
D 432	840	E
B 648	520	C
Began	at A	

Triangle . . A B C	336960	} Double areas collected.
„ A G K	530400	
„ H I K	160512	
Trapezoid, C B D E	345600	
„ E D H I	412032	

Area of whole figure, 8 A. 3 R. $28\frac{1}{2}$ P.

117. Make a plan, and compute the area of a large field from the notes below:—

	A M	
	4350	Diag.
L	3040	430 K
I	2700	500 H
F 692	1022	G
D 480	820	E
B 370	542	C
Began	at A	

Ans. 25 A. 2 R. $4\frac{3}{4}$ P., nearly.

METHOD OF SURVEYING WITH THE CHAIN ONLY.

118. The method of surveying by the chain only, is now the general practice amongst surveyors in this country; and were the ground always perfectly level, there can be no doubt that small surveys, as those of parishes and estates, could be made by it, with an accuracy fully equal to what we can obtain, not only by using a cross-staff, for determining perpendiculars, but even with the aid of superior instruments, such as the theodolite and pocket sextant. Further on, at the end of this section, will be found the common method of reducing measurements made on sloping or uneven ground, to the corresponding horizontal distances.

In surveying with the chain only, it is necessary to measure as many lines as will enable you to divide your survey into triangles and trapeziums; the perpendiculars and diagonals of which are then to be measured by the same scale as that used for laying down your plan; and the areas of the triangles and trapeziums are then easily obtained.

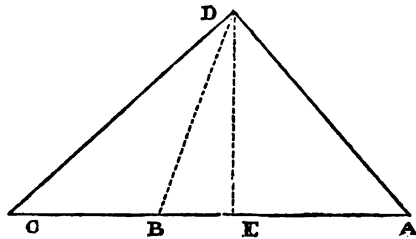
To survey a triangular field by the chain alone.

119. Measure the three sides, leaving a mark on the chain-line of one of them, in order that the distance between the mark and the opposite angle may be measured, to serve as a proof when the plan is laid down. Or, leave marks upon any two of the chain-lines, when the measured distance between the marks must be compared with the same distance on the plan.

EXAMPLE.

Construct a figure, and find its area, from the following notes :—

	B D	Proof line.
	687	
Return	to B	
	DA	
	862	
R	From D	
	CD	
	955	
R	From C	
	AC	
	1265	
	800	B, point for proof line.
Began	at A	



Having constructed the figure, by laying down a line, CA, of 1265 links, from a scale of equal parts, mark the point B 800 links from A: next, take in your compasses 862 from the same scale, and sweep an arc on A, as a centre; after which take 955 in the compasses, and de-

scribe an arc intersecting the former one, which fixes the point D. Lastly, measure upon the plan the length of BD, and see whether it agrees with the same line as measured in the field. If it do not, an error has been made somewhere; either in laying down the figure, or when measuring in the field.

To find the area.—Let fall a perpendicular from D, to the base line CA, measure the length of the perpendicular on the plan, and apply it to the scale by which you are working, which will give you the length in links: then, having the base and perpendicular, proceed as before (100), to find the area of the figure, which is 4 acres, 0 roods, 15 poles; the perpendicular being 640.

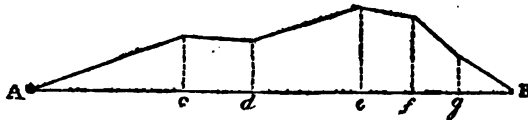
120. If a figure of several sides is to be measured by the chain alone, divide it into trapeziums and triangles, by measuring the diagonals and bases during the progress of the survey; in order that, to find the area, you may only have the perpendiculars to measure by the scale.

Be careful also to measure, in some convenient direction, a proof line to each triangle, as shown in the last example, and a proof line for each trapezium, by measuring both diagonals in the field.—See 107.

METHODS OF MEASURING FIELDS, ETC., WHEN THE BOUNDARY LINES DO NOT RUN STRAIGHT.

121. When the fences of a field do not run in right lines,—as is often the case,—the surveyor measures a straight line, as near as possible to the crooked one, which latter he determines by means of off-sets.

For example,—suppose the waving line from A to B is to be surveyed:—



Place a mark near A, and another close to B; then measure from A towards B, taking off-sets to each part of the fence presenting a curve or an angle; observing, with reference to a curve, to take the off-sets, so that a right line drawn from the end of one off-set or perpendicular to the end of the next, shall neither exclude any portion of the land to be measured, nor include any of that which is adjacent. Perpendiculars, so traced, will divide the space between the straight line and curved boundary, into triangles and trapezoids, of which the areas must be found, as before shown.

The following are field-notes to the above figure:—

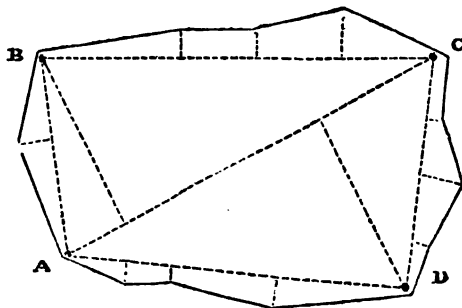
	A B	
	1503	
133	1324	<i>g</i>
173	1187	<i>f</i>
268	1020	<i>e</i>
150	688	<i>d</i>
169	470	<i>c</i>
o	0	{ These ciphers denote that no off-set was taken at A.
Began	at A	

122. It should now be mentioned, that in all surveys it is desirable that the directions of the principal lines, with

reference to the four cardinal points of the compass, or East, West, North, and South, should be shown. If the surveyor be provided with a surveying compass, he has only to observe the bearing, as it is termed, that is, the deviation from the magnetic meridian of any line in his survey, reckoned in degrees and minutes, to enable him to draw a meridian line on his plan, by which the direction of any other line can readily be determined.—(Further on, when we come to treat of the Compass, this matter will be more fully explained.)

If the surveyor have no compass, he must judge by the sun, of the direction in which each main line runs, and note it in his field-book in the manner shown in the field-notes on the opposite page.

123. The figure below shows the method of surveying a very irregular field, by fixing four stations, $A B C D$, connecting them by right lines forming a trapezium, which the diagonal, $A C$, divides into two triangles, $A B C$ and $A D C$. The four lines, $A B$, $B C$, $C D$, and $D A$, are then measured, taking off-sets to every bend or angle.



Notes to the above figure.

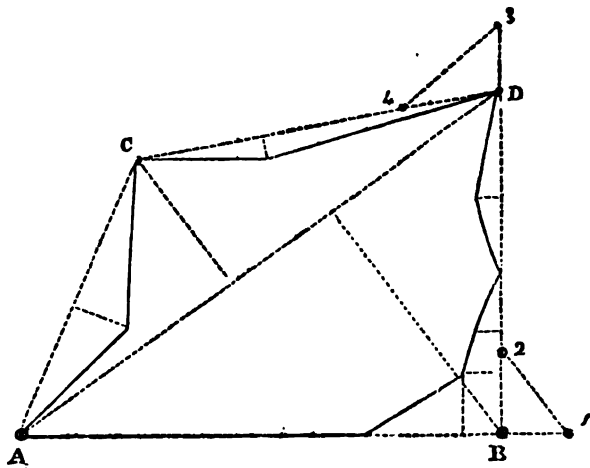
	A C	Diagonal.
	1290	
Perpendicular	884	587
580	205	Perpendicular.
From	A	N. East.
	A D	
12	1050	
82	906	
48	764	
88	412	
30	0	
From	D	Going West.
	C D	
36	722	
58	585	
124	395	
50	182	
20	0	
From	C	Going South.
	B C	
11	1212	
145	975	
83	708	
105	432	
12	0	
From	B	Going East.
	A B	
21	622	
110	350	
15	0	
Began	at A	Going North.

In reference to the survey of the above figure, the stations might be placed either altogether outside of it, or, if more convenient, some might run along the interior, and others be carried outside. A surveyor always walks over his ground before he determines what will be the best method of conducting his survey, and which are the most favourable points for his stations.

123. Let us now suppose that a lake or a wood is to be surveyed, across which we have no means of measuring: in such case it is evident that we must work round the lake or wood.

If we have a cross-staff, or any instrument for taking angles, we may form a square or a rectangle, which shall enclose the lake, whose exact form is then obtained by means of off-sets from the encompassing straight lines; and we can prove the accuracy of our measurements by seeing whether the opposite sides of our rectangle or square be equal.

124. The following is another method, by which a wood, lake or marsh may be surveyed.



Begin at B, setting up marks at A and D to form a right angle at that point, which is to be effected by the cross-staff, or any other instrument. If you have no instrument wherewith to lay off a right angle, form one upon AB towards D, so as to clear the wood (see 55 and 56). Measure the lines BA and BD, taking the necessary off-sets as you proceed; after which set up a mark at C, and measure CD and CA.

To construct the figure, you have the two sides AB and BD and their included right angle, to form the triangle ABD; then on A and D as centres, with the lengths AC and CD in the compasses, describe arcs to cut each other at C, fixing that point and thereby forming the triangle ACD.

Having thus obtained the figure and its diagonal; in order to find the area, you have only to let fall perpendiculars from C and B upon the diagonal, to enable you to calculate the area of the trapezium ABDC; after which you must calculate the areas of all the little triangles and trapezoids, and subtract their sum from the area of the trapezium.

125. Another method of surveying the above figure without forming a right angle is the following:—

Having measured from A to B (see the same figure), continue on, say for two chains, to 1, and there leave a mark, then return to B, and measure towards a mark fixed at D: at the distance of three chains, or less, measured towards D, place a mark, and measure the cross distance from 2 to 1. Again, when arrived at D, prolong BD, and measure any convenient distance to 3, then return to D, and measure towards a mark at C: place a mark two or three chains distance towards C at 4, and ascertain the length of the cross line from 4 to 3. It is evident that when

laying down the plan, you can construct the two little triangles at B and D, having their three sides, and hence the directions of D and C are obtained. Your work will be correct if the measured line A C agrees in length with the same line on your plan when applied to the scale.

Surveyors term this method of laying down angles, working by tie-lines; and with care angles may be laid down by it with great accuracy (see 69).

126. The plan of a river may be taken very easily by fixing up marks at its principal bends, and measuring off-sets from the straight lines joining these marks; but the directions of such straight lines relative to each other must be obtained either by measuring the angles they form, or by taking their bearings with reference to the meridian.

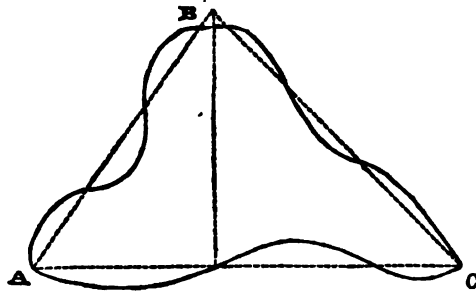


The angles may also be ascertained by means of *tie-lines* as in the last example; to effect which you would produce A B the length of two, three chains, or more, according to circumstances, and proceed to determine the direction of B C, &c. in the way which is therein explained.

127. *Method of computing areas by "casting."*

Surveyors have a method of computing areas called "casting," which is employed when the boundaries of a piece of ground run in very irregular lines. Having laid down the figure correctly, as surveyed by means of measured lines and off-sets, they draw straight lines forming a triangle or any other figure, in such a manner as to include as much of what does not belong to the survey, as is excluded of what does belong to it.

As an illustration of "casting," we will suppose the waving lines of the figure ABC to be the true lines of the survey.



Now, to find the area of such a figure by first forming, either within or without it, a large triangle, computing its area, and then going through all the minor calculations occasioned by a great number of off-sets, is manifestly a very tedious process: to avoid which surveyors construct a right-lined figure, as ABC , including as much space as is contained within the irregular boundaries, of which they compute the area, and take such area in lieu of that of the true figure.

At page 111, 3rd edition, Mr. Nesbit gives some mechanical methods of equalizing the portions taken in and excluded by the straight lines, which are unsuited to the purpose of this treatise, especially as I believe that most surveyors judge the portions by the eye alone.

Sufficient examples have now been given of the methods of surveying single fields, or figures of various form ; as also of *plotting* or making plans of them, and computing their area. We will, therefore, proceed a step further, and see how surveys of greater extent may be made.

128. *To survey ground, divided into three, four, or more fields.*

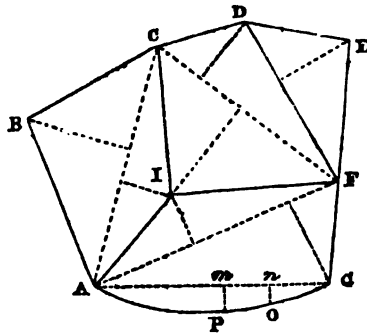
Let the diagram below represent a property, consisting of five small fields. In order to determine what will be the best way of making a plan of the whole, walk over them, and fix a plan of them in your mind. On examination, you find that, with the exception of one curved fence (A to G), all the lines bounding, as well as those which divide the property into fields, are right lines: you therefore decide, that to survey each field separately, and afterwards unite the whole into one plan, is the best mode of proceeding.

You will find it very useful, as a guide for laying down the plan, to make a rough sketch of the figure ; having done which, place marks at every angle formed by the fences, and begin the measurements. The ground to be surveyed presents two trapeziums, ABCI and CDFI ; a triangle, DEF, and the nondescript figure, AIFG.

To determine the trapezium, ABCI, measure from A to C and the perpendiculars I and B ; with these you can lay down that field. Next, for the trapezium, CDFI ;

measure IF and the diagonal, FC , with the perpendiculars to I and D , and, with IC of preceding figure, you have data enough to form the second trapezium. For the triangle DEF , you have the base, DF , in the preceding figure, which had better, however, be measured, as a check, and perpendicular to E . Lastly, measure the diagonal, FA , with the perpendicular to G and I , by which the trapezium, $AIFG$, can be laid down, and along AG measure the off-sets, no and mP .

Note.—Be careful to measure the diagonals from B to I , from I to D , and from I to G , as checks upon your work.



	A C	Diag.
	790	
B 360	445	Per.
Per.	336	172 to I.
0	0	0
Began	at A	Going North.

TO SURVEY GROUND DIVIDED

	GA	
	722	
<i>p</i> 72	325	<i>m</i>
<i>o</i> 53	180	<i>n</i>
0	0	0
From	G	
	AF	Diag.
	830	
Per.	486	160 to I.
G 278	125	Per.
0	0	0
Return	to F	
	FD	
	616	
Per.	446	272
0	0	0
Return	to F	
	FI	
	510	
0	0	0
From	F	
	CF	Diag.
	730	
Per.	350	346 to I.
D 215	155	Per.
0	0	0
R from	C	

The calculation complete of this survey will be of use to the learner.

360 } per.	215 } per.
172 }	346 }
532	561
790	730
47880	16830
3724	3927
420280 double area, ABCI.	409530 d. area, CDFI.

616	278
272	160
1232	438
4312	830
1232	
	13140
167552 d. area, D E F.	3504
	363540 d. area, AIFG.

53	72	397
180	53	72
4240	125	794
53	145	2779
9540 d. area, G n o.	625	28584 d. area, A P m.
	500	
	125	
	18125 d. area, n m P o.	

Trapezium A B C I	420280	} Double areas collected.
" " C D F I	409530	
Triangle . . . D E F	167552	
Trapezium A I F G	363540	
Triangle . . . G n o	9540	
Trapezoid . n m P o	18125	
Triangle . . A P m	28584	

2) 1417151

7-08575

4

34300

40

13-72000

Area of the whole, 7 A. 0 R. 13½ P.

129. Lay down a plan and compute the area from the following notes : —

L from	A D	
	470	
	160	267 to E.
	A	
B 217 Began	A C	Diag.
	517	
	322	325 to D.
	302	
	at A	

Ans. Area, 2 A. 0 R. 4½ P.

130. Lay down a plan and compute the area from the following notes :—

F 267 From	G C	Diag.
	463	
	288	275 M.
	127	
R from	G	
	M G	
	315	
	M	Going North.
Per. From	C A	
	314	
	244	220 M.
	C	
D 200 Per. From	E C	Diag.
	454	
	223	Per.
	75	180 F.
L from	E	
	D E	
	296	
	D	Going West.
C 66	A D	Diag.
	610	
	304	Per.
	263	260 E.
Began	at A	Going North.

Ans. 3 A. 1 R. 33½ P.

131. A very little consideration will enable any one to see that the kind of patch-work presented by the last examples would, if tried on a more extensive scale—such as in the survey of a considerable estate—not only prove very tedious, but likewise inexact: for the method of laying down one figure, and upon it as a basis constructing another, patching thus together a number of fields, would cause errors to keep increasing, without the possibility of maintaining any sufficient check upon the work.

132. Surveyors commonly divide an estate or a parish which is to be surveyed, into one, two, or more great triangles, and the angular points being visible from each other, they are enabled to measure straight lines, connecting them, by which the triangles can be laid down upon paper. In measuring these long lines, notes are kept in the field-book to show at what distances along them fences, roads, rivulets, &c., are crossed. Other lines within the large triangles are then measured; and off-sets are taken to boundaries, fences, &c.; all observations being carefully noted in the field-book, until sufficient measurements have been made, by which to lay down all the boundary lines, fences, &c., contained within the limits of the ground to be surveyed.

It will be necessary to attend to the following rules in carrying on a survey of this description:—

1. Be in no hurry to commence operations, but walk two or three times over the ground in order to get a perfect idea of it: and to help your memory, a rough sketch on paper by the eye is recommended.
2. Select two points from which you can see to a considerable distance around; let these stations be as far from each other as possible; let them be near the boundaries of the ground, and so situated that

a line connecting them shall be a kind of diagonal across it, forming what surveyors call a "main line;" which is to serve as a base for after operations.

3. Fix on a suitable station on each side of the "main line" near the boundary of your work, to which lines are to be measured from each end of it; thus forming two large triangles, one on each side of the base line.
4. On the sides of the triangles already formed, smaller triangles must then be marked out, so as to comprise all the ground to be surveyed.
5. Lines are to be run from any station laid down, or from any part of a line connecting two of them, in directions most convenient for obtaining the fences, taking off-sets to such objects as present themselves, determining the boundaries of rivers, roads, &c.

The following plate represents a survey, with the field-book from which it was drawn; and as all the measurements are laid down on the plan with great care, it is hoped that the study of it will sufficiently illustrate the principle of this kind of surveying, as also show that when the ground is tolerably level, a survey so conducted, if not of too great extent, need not yield in point of accuracy to any other known method.

The field-book entries are in accordance with the recommendation given under the proper head (see 90); the principal of which are, that you begin at the bottom of the page and write upwards, and that the fences and boundaries of rivers, roads, &c., be drawn in the field-book opposite the respective distances, at angles or otherwise, roughly representing the inclinations on the ground which they present to the lines measured.

133. METHOD OF CONDUCTING A SURVEY WITH THE CHAIN.

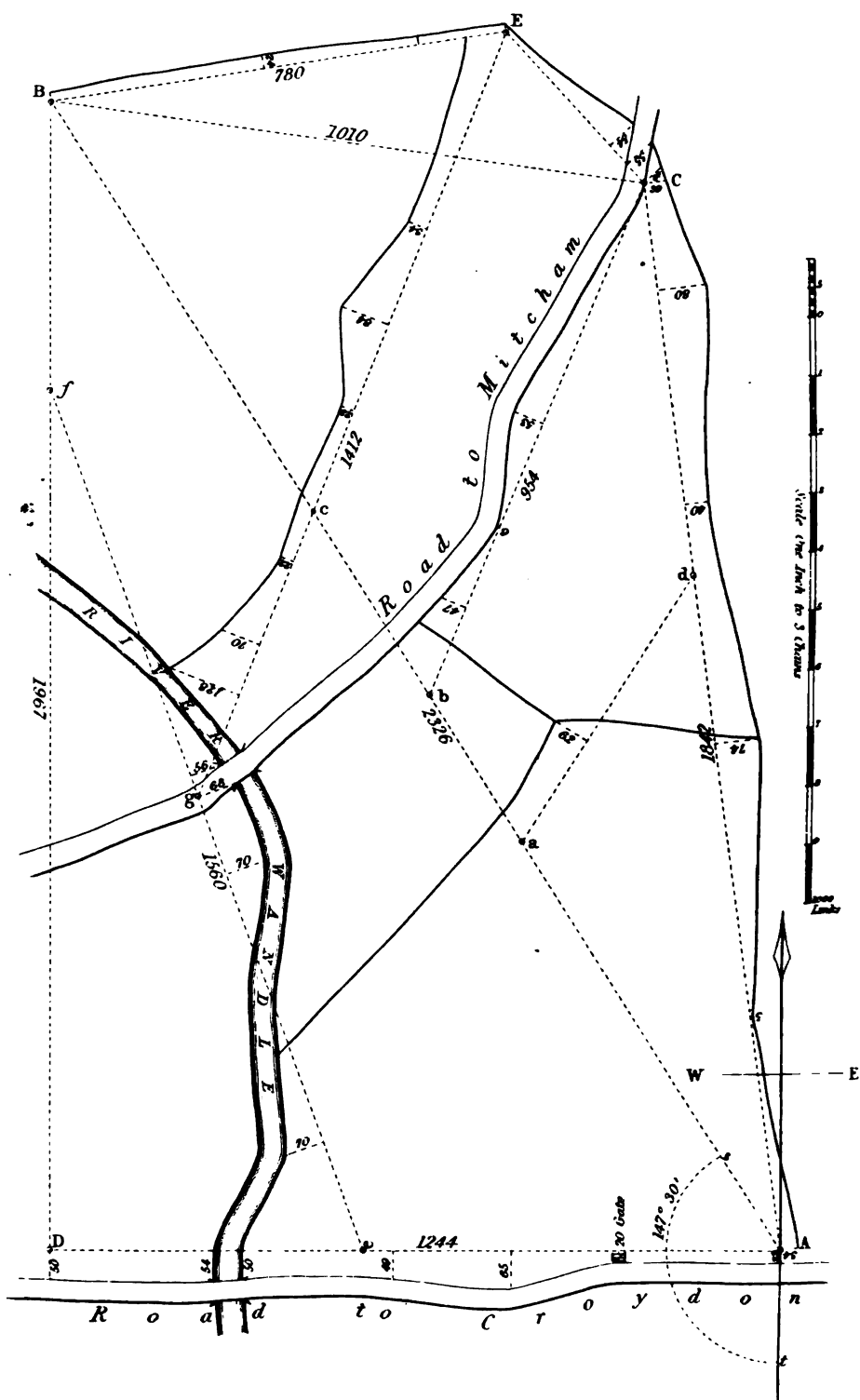
After a careful examination of the ground, the points marked A and B are found to be eligible stations to form the extremities of the base line, as they are not only visible from each other, but poles set up at D and C can also be seen from them both.

Marks having been set up so as to define a straight line running between A and B, the measurement is begun at A.

But it is desirable, if we have a compass, to ascertain how the line A B is situated with reference to the magnetic meridian; as all plans should have a north and south line laid down on them, from which the direction of any line on the plan can then be readily seen. There are surveying compasses of various kinds, but the only one of which mention will appear in this book, is the prismatic surveying compass, an invention of the late Mr. Schmalcalder, optician; a description of which, with instruction how to use it, will be found further on, under the head of "Prismatic Compass." The student will there also find an explanation of the difference between the magnetic and true meridians, called the variation of the needle. We now return to the business of our survey.

Measurements on the line A B.

At $\odot A$ we find the direction of B is $147^{\circ} 30' N.W.$ (all westerly bearings being reckoned from the south point of the meridian). The first entry in the field-book will therefore be, putting each portion into its proper column—*From $\odot A$ Go $147^{\circ} 30' N.W.$* The chaining is then carried on in the direction of B. At 820 links, a point *a* appears likely to be useful as a secondary station; a peg is therefore



40	355	⊙ C	547	⊙ d
55	312		251	
54	267		210	
7	0		From ⊙ a	
From ⊙ E			1967	⊙ B
12	780	⊙ E	1474	⊙ f
	712		1176	
15	628		1115	
24	373		698	
15	0		Road	650
From ⊙ B	go east		From ⊙ D	go North
	954	⊙ b	50	1244
	854		54	950
	787	47	50	905
	637	6	40	700
	446	33	49	655
From ⊙ C		Road	65	452
	1412	⊙ g	20	275
	1332		23	0
	1290		From ⊙ A	go West
	1223	128	34	1842
	1130	70	5	1440
	978	22	74	968
	890			953
	700	⊙ c		680
	544	23	40	556
	367	84	80	180
From ⊙ E		34	39	0
	1560	⊙ f	From ⊙ C	go South
River	1112		1010	⊙ C-
	1023		Road	971
	861	56		658
	845		From ⊙ B	go East
g ⊙	824	68		2326
	798			1520
	684	70		1483
	550			1252
River	437		Road	1222
70	377			1115
From ⊙ e	200			882
			From ⊙ A	⊙ a
				go 147° 30' N.W.

driven at that place and an entry made, as seen in the field-book. At 882 links we come to a fence, and we are careful to give a slight slant to the short line drawn on each side of the number in the field-book, showing nearly the angle at which it is crossed by the chain. At 1115 we reach a point that will serve us when we come to trace, by means of off-sets, the Mitcham road. At 1222 and 1252, respectively, we cross the boundaries of the road; and at 1483 drive a peg for $\odot c$, to facilitate the putting in of an irregular fence running towards E; (points are thus often fixed and noted in the field-book, upon the chance of their turning to account when running secondary lines). The measurement of the line A B is found to be 2326 links. Write $\odot B$ in the right hand column, and draw two lines across the centre column to show that the measurement of the base line is complete. Thus the middle column always contains the stations *from*, and the right column those *to*, which measurements are made; as in the field-book before us we see $\odot A$ at the bottom, and $\odot a, b, c$, and B on the right.

Measurements on the line B C.

The next measurement is from B towards C, lying *east* of B; the distance measured is 1010 links, crossing a fence at 658, and a boundary of a road at 987 links.

Measurements on the line C A.

From $\odot C$ it is 39 links to the fence on the left, an entry is therefore made of 39, opposite an 0 in the chain column; the fence then recedes from the chain line, and at 180 links forms a bend, which is 80 links from the chain, while at 556 it is only 40 links. At 680, fix a station *d*, to be used afterwards: at 953, cross fence: at 968, the fence has again receded, and is 74 links from the chain; but at

1440, it approaches to within 5 links of it. The whole distance from C to A is 1842, and the fence is there 34 links on the left.

Having thus measured the lines, A B, B C, and C A, we can lay down the triangle, A B C, which embraces nearly one half of the ground to be surveyed. The lines A D and D B are now to be measured, that we may be able to construct another triangle, A D B, upon the base line A B, which then becomes the diagonal of a large quadrangle, A D B C.

Measurements on the line A D.

The line A D skirts a high road ; and if we take off-sets at every bend of the latter up to its nearest boundary, and also measure the breadth of the road, we can have no difficulty in laying it down accurately on a plan.

We observe, that D lies west of A, and note it in the field-book. At A, the road is 23 links on the left ; 275, there is a gate in the fence, which is 20 links from the chain ; 452, a bend, 65 links from chain ; 655, the off-set is 49, and the breadth of the road 40 ; at 700, fix a station, *e*, which may be of use for putting in the river ; at 905, margin of river, over which is a bridge 50 links to the left ; 950, opposite bank, with 54 links off-set to bridge. 1244 is the whole distance, and it is 50 links from D to the road.

Measurements on the line D B.

The direction is nearly north. At 650 and 698, we cross the boundaries of a road ; and at 1115 and 1176, those of a river ; at 1474 is a convenient point for a station, *f*. The whole line D B is 1967 links.

We can now construct the two triangles, A B C and A D B, comprising the whole of our ground, except a

small triangular portion at its northern end. To obtain which a point, E, is chosen, and the lines BE and EC being measured, this little triangle can be formed.

It is quite unnecessary to describe, with the same degree of minuteness, the measurements of the rest of the lines, we shall therefore briefly show the several purposes for which they are run.

The line ef.

A station was fixed at *e*, while we were measuring on AD, and another at *f*, on DB, for the purpose of planning the river by means of off-sets taken on both sides of a line connecting *e* and *f*; and by reference to the field-book it will be seen that many off-sets were taken. Moreover, if the line *ef*, when measured on the plan, be found to agree with the distance chained, a proof is afforded of the accuracy of the previous work.

The line Ec g.

Station *c* was fixed, that we might be able to put in a long line of zig-zag fence, running between E and the river. The measurement of a line from E, passing through *c*, gives the means of surveying this fence with great ease, by means of off-sets. It is produced to *g*, in the line *ef*, to serve as a check line.

The line Cb, affords the means of surveying a considerable portion of the road running south-west from C; while it at the same time serves as a check on the survey.

The line ad, crosses a fence, and also fixes, by means of an off-set of 62 links, the junction point of three fences.

134. *To construct a plan from the field-book.*

By reference to the field-book, it appears, that a line, 2326 links long, forms the base of the survey, and that by compass it bears nearly north-west, forming an angle of $147^{\circ} 30'$ with the south pole of the needle. (*See Prismatic Compass.*) Draw a line on your paper in any convenient direction, and make it 2326 long, from any scale of equal parts (the scale to which the accompanying plan is drawn, is that of an inch divided into three parts, each part being the length assigned to a chain). Write the letter A at one end of the line, and B at the other, surrounding the points formed by the extremities of the line with a little circle, $\odot$, to signify station.

The next step is to lay down a meridian line, which had better be done at the point A; this is effected by simply drawing a line, A t, so as to make the angle, $s A t = 147^{\circ} 30'$; when the line t A may be produced, and another drawn at right angles across it, denoting the east and west points of the compass.

Referring to the field-book, it appears that the second line measured was from B, the end of the base, in an east direction to a point C, and that its length is 1010 links. Take this number then in your compasses, and with one point at B, sweep an arc on its eastern side (according to your meridian line).

We must now look in the field-book for a line running between A and C, which we find to be 1842 links. Take this distance in the compasses, place one leg at A, and with the pencil point describe an arc to cut the one previously swept from B; their intersection fixes the point C.

The field-book now shows that a line from A was measured in a west direction, 1244 links to a point D, and also

that between D and B a line was run of 1967 links. With these lengths in the compasses, and on A and B as centres, describe arcs intersecting each other, which will fix the point D. Thus the two great triangles are constructed; and the triangle BEC having been also formed by taking the lines BE and EC from the field-book; the next proceeding is to fix on the main lines, the situations of secondary stations, crossings of fences, and other details.

On the line AB.

Mark the point *a* at 820 links, and at 882 the crossing of a fence, drawing a line for a short distance on each side; at 1115, $\odot b$; at 1222, and 1252, the boundaries of the road; at 1483, $\odot c$; at 1520, a fence.

On the line CA.

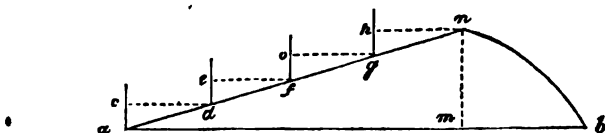
Set off 39 for the off-set on the left at the station; at 180, draw a perpendicular and make it 80; at 556, another perpendicular of 40 links; at 680, mark the point of $\odot d$; at 953, a fence crosses the chain line; at 968, a perpendicular of 74 links; at 1440, a perpendicular of 5; and at A, one of 34. Join the ends of these perpendiculars or off-sets, by a line passing through all the points, and you obtain the run of the fence between C and A.

In the same way, go over all the lines measured, uniting the fences, lines of road, &c., wherever it appears evident that a junction must take place, according to the directions in which your lines, crossing the chain lines, are drawn in the field-book.

It must be needless to go into greater detail than has been done already; sufficient information having been given to enable a student of ordinary intelligence, having the plan and field-book before him, to understand this method of surveying.

OF LINES MEASURED ON UNEVEN, OR SLOPING, GROUND.

135. All lines laid down upon a map or plan are termed horizontal lines; that is, they are of the same length as if they were all measured between points at the same level. Hence, in all surveys, every line measured upon sloping or undulating ground, must be reduced to its corresponding horizontal length, before it can be plotted or laid down on paper.



The above diagram represents a section of a hill, standing on the base ab . Now, it is evident that the curve line, $adfgnb$, describing the form of the hill, is longer than the ab ; and therefore, as the distance ab is all that can be allowed in a plan, if a surveyor measures the curve surface of the hill, he must of necessity reduce it to the true horizontal distance.

There are various ways of reducing sloping lines to horizontal ones, but I believe that in practice the following simple method is commonly adopted:—

We will suppose that the slope an is to be measured downwards, and with the chain. One person holds an end of the chain at n , while another stands with an off-set staff at g , 30, 40, or 50 links down the slope, according to its steepness; the portion of the chain used is then to be drawn tight while held horizontally, represented by the line hn ; an arrow is then placed at g . In this way a succession of short horizontal lines, hn , og , ef , and cd ,

will give us the length of am ; which is the horizontal distance corresponding to the *hypotenusal* line, an .

A measuring tape is preferable to a chain for thus measuring slopes, as it is easier to draw it tight; and when one end is held up, so as to make the line of tape horizontal, a pebble dropped on the ground from its extremity will indicate the point from which the next length is to be taken.

The above short elementary course of surveying with the chain is sufficient for most persons who do not intend to become professional surveyors. To such as aim at a thorough knowledge of what may be termed *Civil Surveying*, Mr. Nesbit's Treatise on Practical Land-Surveying is recommended as a very useful work.

SURVEYING WITH INSTRUMENTS.

SECTION III.

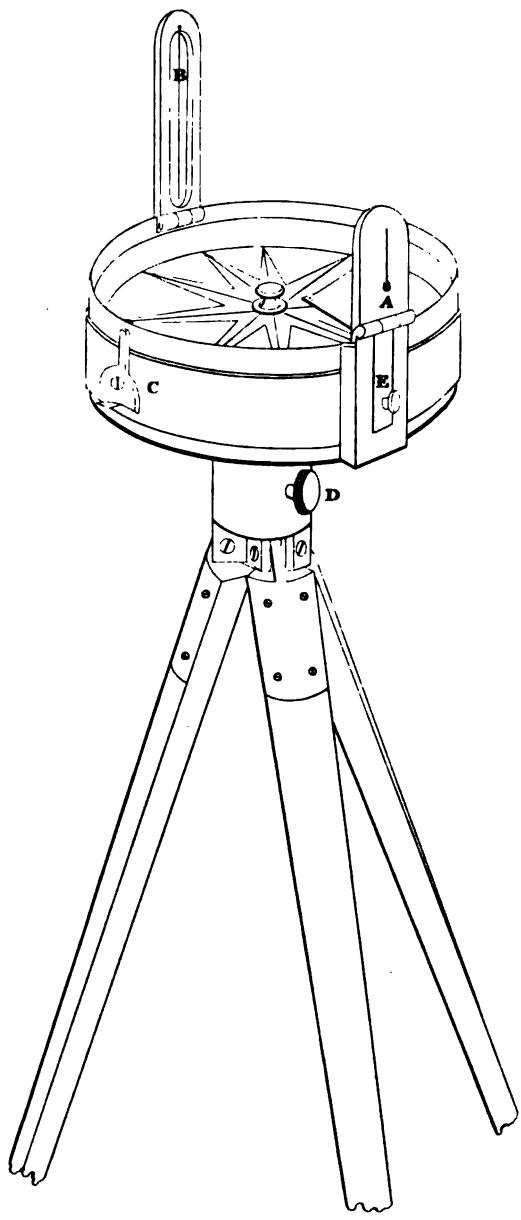
ON SURVEYING WITH THE PRISMATIC COMPASS.

OBSERVATIONS.—PRISMATIC COMPASS.—TAKING BEARINGS.

IMPLEMENTS REQUIRED.—TO SURVEY A ROAD BY THE COMPASS, AND PROTRACT IN THE FIELD.—THE SIMPLEST METHOD OF SURVEYING A PORTION OF GROUND; SUCH AS A MILITARY POSITION.—TO FIND YOUR PLACE IN A SURVEY OR SKETCH, BY MEANS OF TWO BEARINGS.

THE preceding section contains a short but useful course of surveying by means of lines measured with the chain, whereby surveys of moderate extent can be performed with much accuracy. But the method of linear surveying is only suited to a country which is neither mountainous, nor thickly wooded, and would therefore be almost useless if applied amidst the Alps and Pyrenees, the forests of America, or the jungles of India. It is requisite, therefore, that methods of surveying should be general in their application; suited alike to all countries—whether mountainous or flat, wooded or bare, open or enclosed. Besides, even under the most favourable circumstances, chain surveying is of necessity limited to an extent of a few square miles, and is altogether inapplicable to the surveying of roads and rivers.

PLATE I.



THE SURVEYING COMPASS.

All extensive surveys of whatsoever nature, and all maps and plans which are required for military purposes, must be made with the aid of instruments for measuring angles ; —such as the theodolite, sextant, compass, &c.

PRISMATIC COMPASS.

When very great accuracy is not required, and the survey be moreover of limited extent, the *Prismatic Compass* may be used with advantage ; and I entirely concur in an opinion with regard to the value of that instrument, expressed by an able surveyor, S. B. Howlett, Esq., chief draftsman of the ordnance department, who observes (Professional Papers, Royal Engineers, vol. i.) : —“ The method of surveying by the prismatic compass appears to be so valuable for military purposes, and the process so well adapted to teach the principles of surveying, that it might perhaps be found worth consideration, whether it should not be perfectly understood, before a theodolite be put into the hands of a pupil.”

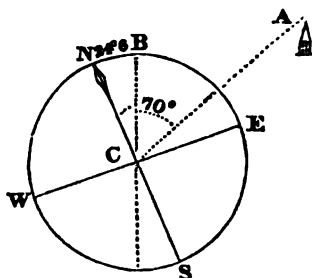
The prismatic surveying compass, known as Schmalcalder's, when mounted on a stand, and having the card divided to 20', that is, each degree into three parts, enables the observer to obtain a bearing to within three or four minutes of a degree, by estimation.* When held in the hand, a bearing may be depended on to about fifteen minutes, provided the wind be not so violent as to shake the hand of the observer ; when such is the case, it is usual to watch the vibration of the divisions on each side of the vertical hair, and take the mean. I have found it most

* Messrs. Troughton and Simms, 136, Fleet Street, have lately divided the cards of their smallest prismatic compasses to twenty minutes instead of to half a degree, as formerly, which I consider to be a great improvement.

convenient when the card is divided into twice 180 degrees, instead of having it numbered from 0 to 360 degrees. The stand is better without levelling screws; they are troublesome, and, I may say, almost useless; for the card is easily made level enough to play freely, by shifting the legs of the stand: these should be between five and six feet long, for the convenience of the observer, and that the instrument may be above the height of brushwood, &c., which often impedes the view.

TAKING BEARINGS.

In surveying with the compass, the bearings of objects are taken from the *magnetic meridian*. Let NS represent



the magnetic needle or meridian, W the west, and E the east; and suppose the sights of the compass are directed to the spire A; then if the angle NCA be 70° for example, the spire is said to bear 70° north-east, or 70° from the magnetic north towards the east.

The *variation* of the needle is its deviation from the true north. In this figure, the angle NCB represents the variation, BC being considered as the true meridian. The variation is now about 24° west, at London.

IMPLEMENTS REQUIRED.

Having made himself master of the instrument, so as to be able to take bearings, I recommend the student to attempt the simplest kind of surveying, viz. that of a road ; the mode of doing which I shall endeavour to render very easy to him. He will require to be provided with a sketching case, about ten or eleven inches square, an ivory rectangular protractor, or plain scale, such as every case of mathematical instruments is furnished with, and a black-lead pencil. His paper, asses-skin, or what is preferable to either, a piece of paste-board, fits into the sketching case, and must be ruled over with very fine lines, exactly *parallel* to each other, and at *unequal* distances, varying from a quarter to three-eighths of an inch apart.* The purpose to be answered by ruling the lines at unequal distances, we shall presently see. The protractor is six inches long, and an inch and three-quarters wide, having *across it* a number of very fine lines at right angles with its length, and at *equal* distances from each other. These lines are regulated so as to form a scale of four inches to a mile, but may likewise be used for paces or yards.

The student is now prepared to take bearings along the road.

* *Sketching-blocks* have lately been used at Addiscombe College, for sketching and plotting in the field, and found very convenient. Each sheet of paper composing the blocks has the parallel lines printed on it from a steel plate, which not only ensures the accuracy of their parallelism, but gives the lines very fine, which is a desideratum. A useful size for a *block* is twelve by ten inches, and it fits into a patent leather case, which may be slung over the shoulder or attached to a saddle. They are made by Messrs. RANVES, 150, Chesapeake.

TO SURVEY A ROAD BY THE COMPASS, AND PROTRACT IN
THE FIELD.

The compass is set up at the point from which we purpose to start, as A (plate II., fig. 1); and care being taken that the card be level, so as to play freely, a mark is placed at B, where the road turns to the right; the sights of the instrument are then directed to the mark at B, and we find, when the card has settled, that the vertical hair cuts the 29th degree; the bearing of B is therefore 29° north-east—the mark at B lying towards the east point from the magnetic north.—I would observe, that in ordinary road sketching, it is not usual to set up any marks: some object will present itself, which must be kept strictly in line when pacing the distance; thus, much time is saved.

Next, to protract, or lay down the bearing of B upon our paper, which has upon it the parallel lines at *unequal* distances, to be considered as *east* and *west*, and therefore not meridian lines, which are north and south.

The protractor has across it, as we have already noticed, a number of lines. Now, fix on any convenient part of the paper, make a dot, and surround it with a small circle, thus ○, which denotes a station. Place the centre of the protractor at this point, and endeavour to make any one of the lines which are drawn across it, to coincide with one of those upon the paper, being careful to keep its centre very exactly on the point. This being effected, the protractor is adjusted, that is, lengthwise it will lie north and south, while its ends will, of course, be east and west. Make a small mark on the paper at the 29th division or degree, when the protractor may be removed. A line is then drawn from A, through that mark, which line will bear 29° N.E. You now measure the distance

from A to B, either with the chain, or by pacing the regular marching step of thirty inches. To lay off the distance measured: apply the edge of the protractor, which has a scale marked on it, to the line on your sketch, or use a slip of paper upon which a scale of any size you please has been prepared, and mark off the distance. Finally, trace lines, as shown in the figure, to represent the sides of the road, and the first station is completed.

A mark is next placed at C, and its bearing taken from B, namely, 59° N.E.

When we come to take the bearing of D from C, we find the sights of the instrument turned to the left of the magnetic north, while the vertical hair cuts the card at the 156th degree. Now, in the common mode of reading a bearing, we should say that D bore 24° N.W.; but our compass card reads, from north round to south, 180° ; and then, from south round to north, 180° , to complete the circle of 360° . Consequently, all bearings lying on the *west* side of the meridian, are read off from south towards the north; and therefore in the present instance, the bearing of D is 156° N.W.: that is, 156° from the south pole of the needle, round towards the north pole; and as this falls between the W. and N., it is styled north-west.

The expression of bearings may, however, be simplified, if we distinguish them only as *east* and *west*; we shall, therefore, cease to designate them as being so many degrees north-east, south-west, &c., and term all bearings taken from the north pole of the needle, up to 180° , as *east*; while such as are measured from its south pole will be *west*.

Fig. 2, plate II. represents the paper as prepared with parallel lines. The protractor is adjusted to station A, for laying down a bearing from north to east, and on to south. At $\odot$ C, it is likewise adjusted, but reversed in its position, for the purpose of laying off the bearing of D, which, from

from A to B, either with the chain, or by pacing the regular marching step of thirty inches. To lay off the distance measured: apply the edge of the protractor, which has a scale marked on it, to the line on your sketch, or use a slip of paper upon which a scale of any size you please has been prepared, and mark off the distance. Finally, trace lines, as shown in the figure, to represent the sides of the road, and the first station is completed.

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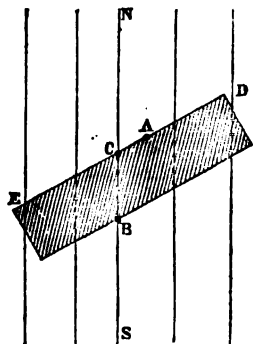
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what has just been observed, must necessarily be reckoned from south, running towards north, passing by west, the situation of which is indicated by 90° on the protractor, the west point being at right angles, or 90° from south.

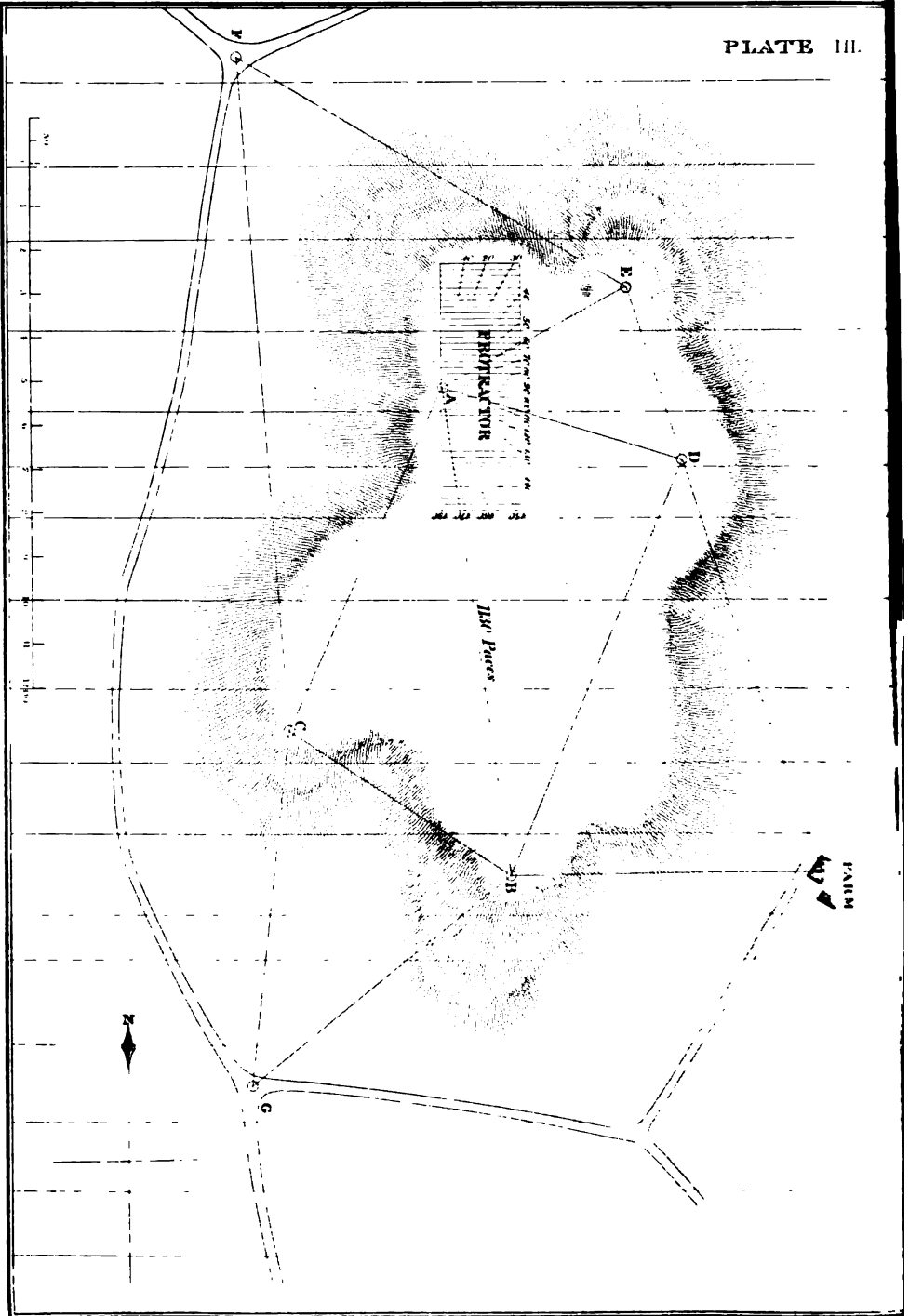
When a protractor is not furnished with cross lines for its adjustment, by the east and west lines drawn on the paper, these may be considered as meridians (north and south); by means of which, bearings are laid down in the following manner:—Suppose that we want to protract a bearing of 60° E. from a point A. Place the centre, C, of



the protractor on any meridian, NS, and turn it as on a pivot, until the 60th degree, reckoning from E, coincides with the same meridian at B. The protractor is then moved up or down, being careful to preserve its position on the meridian, until the upper edge touches the point A, when a line drawn from C through A will make the angle $\angle NCD = 60^\circ = \angle ECB$.

It may be as well to mention here, that when surveying a road, or river, &c., with the compass, bearings need only be taken at every *second* station; as will be seen when we come to speak of surveying with a theodolite and by the needle. To explain this now would only embarrass a beginner.





THE SIMPLEST METHOD OF SURVEYING A PORTION OF
GROUND;* SUCH AS A MILITARY POSITION.

THE paper must be ruled with parallel lines at unequal distances, as before.

Previously to commencing the sketch, it is best to go over the ground and examine it, so as to fix a plan of it on the mind. Then select a few prominent points for stations, from which bearings are to be taken to all conspicuous objects contained within the limits assigned to the sketch; such as houses, remarkable trees, a windmill, church steeple, &c. Next, select the longest and most level space on which to measure a base, which may be either on the summit of the ground you are to sketch, or along the bottom, as most convenient.

Plate III. represents a hill, partly surrounded by a road, of which our object is to take a military sketch with some degree of accuracy. On inspection, it is found that the direction A B is most favourable for the base line. E, D, C, are situations eligible for stations. Now, the compass being placed at A, the bearing of E is taken, namely, 61° E. D is found to bear $106^{\circ} 30'$ E. B, $172^{\circ} 20'$ E. C, $24^{\circ} 30'$ W. Protract these several bearings, by marking a point, A, on the paper, in such a situation as will admit of the whole contemplated sketch being contained on the sheet, and adjusting the ivory protractor to the lines, as on the former occasion, it will then lie in the position that is shown in the figure. Measure the base A B. The mean of three times pacing it over gives, suppose, 1130 paces, of

* The term *ground* is generally to be understood as applied in contradistinction to a flat or a level; so, whenever it is met with in the course of this work, hills or elevations will be meant.

TO SURVEY A ROAD BY THE COMPASS, AND PROTRACT IN
THE FIELD.

The compass is set up at the point from which we purpose to start, as A (plate II., fig. 1); and care being taken that the card be level, so as to play freely, a mark is placed at B, where the road turns to the right; the sights of the instrument are then directed to the mark at B, and we find, when the card has settled, that the vertical hair cuts the 29th degree; the bearing of B is therefore 29° north-east—the mark at B lying towards the east point from the magnetic north.—I would observe, that in ordinary road sketching, it is not usual to set up any marks: some object will present itself, which must be kept strictly in line when pacing the distance; thus, much time is saved.

Next, to protract, or lay down the bearing of B upon our paper, which has upon it the parallel lines at *unequal* distances, to be considered as *east* and *west*, and therefore not meridian lines, which are north and south.

The protractor has across it, as we have already noticed, a number of lines. Now, fix on any convenient part of the paper, make a dot, and surround it with a small circle, thus ⊙, which denotes a station. Place the centre of the protractor at this point, and endeavour to make any one of the lines which are drawn across it, to coincide with one of those upon the paper, being careful to keep its centre very exactly on the point. This being effected, the protractor is adjusted, that is, lengthwise it will lie north and south, while its ends will, of course, be east and west. Make a small mark on the paper at the 29th division or degree, when the protractor may be removed. A line is then drawn from A, through that mark, which line will bear 29° N.E. You now measure the distance

PLATE 2.

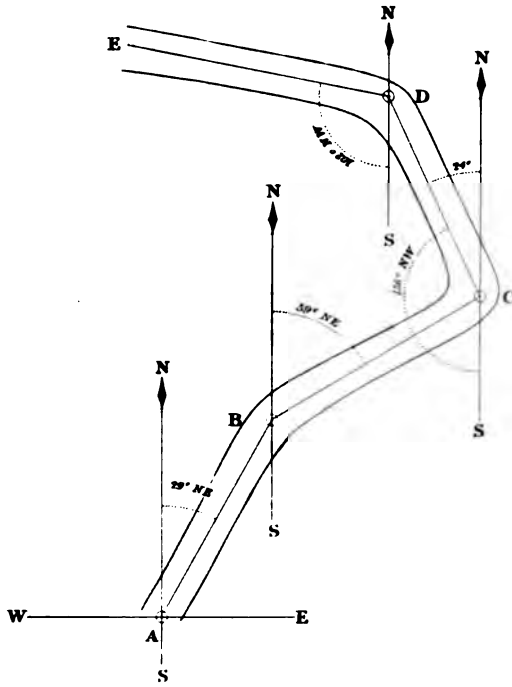
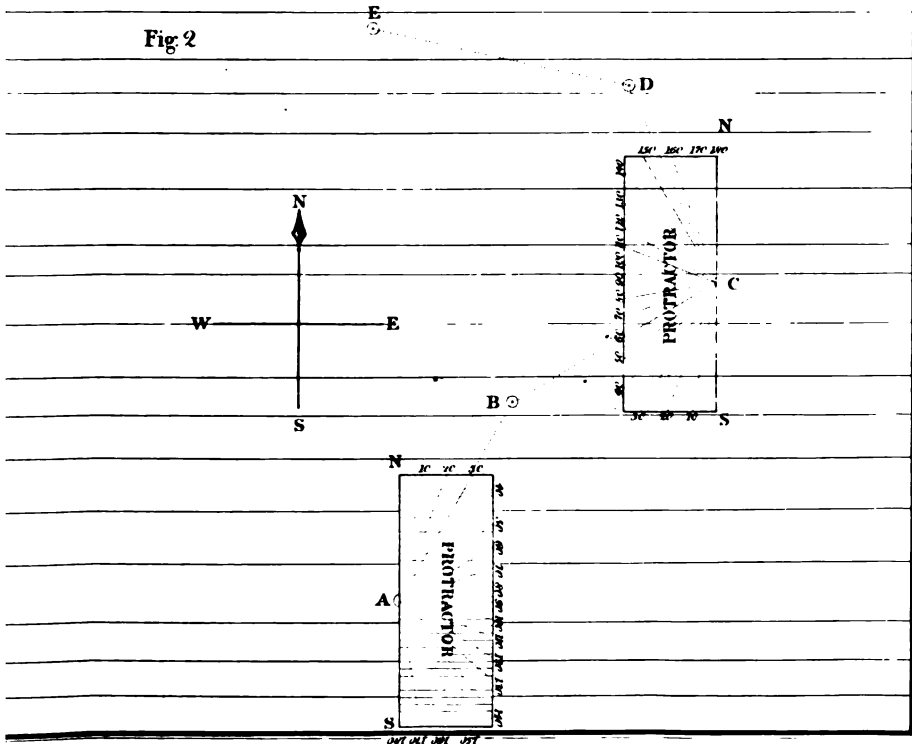


Fig 1

Fig 2



36 inches each.* Lay your scale along the line which indicates the bearing of B, and mark off the number of paces, which fixes the point B.

Again, plant the compass at B, and take the bearing of C, 124° W.; of A, $172^{\circ} 20'$ W.; of E, 11° E.; of D, $22^{\circ} 30'$ E. It will be remarked that the bearing of B from A, and that of A from B, give the same number of degrees and minutes: they form, in fact, alternate angles with their respective meridians, and present, when laid down, the same straight line; furnishing a proof that the bearing taken at A was correct.

The several bearings taken from B are now to be protracted, and the intersections with the lines drawn from A, fix the points C, E, and D.

The observer should now look around, and notice what objects are visible, that it may be advantageous to determine, with a view to assist him in sketching, and filling in his work. For this purpose a bearing must be taken to the farm-house; also to the point G, where a road turns off. The farm bears 89° E., and G, $50^{\circ} 30'$ W. These two bearings are then to be protracted. Proceed with the compass to C, and take the bearing of G from thence, 6° W., which, on being laid down, cuts the bearing taken from B, and determines G. While at C, it is perceived that the point F, where a road branches off, must be fixed: a bearing is therefore taken to F, namely $175^{\circ} 30'$ W. The compass is then carried to D, and the position of the farm-house is decided by a bearing that cuts the one taken from B.

It is a maxim in surveying, that when determining any points of importance, both acute and obtuse intersections

* The measurement of lines by pacing is only to be permitted in rapid military sketching. When greater accuracy is required, the chain must be used.

are to be avoided as much as possible. The nearer an intersection approaches to a right angle, the better : hence, in selecting primary stations, we should endeavour to have them so placed, that bearings which determine them shall intersect or cut each other as near at a right angle as circumstances will permit.

This observation applies particularly to the kind of rough surveying now under consideration ; for it is manifest that some degree of error must attend every operation performed ; for instance, the base line is measured by pacing—our compass only gives a bearing to within three or four minutes of the truth—the protractor is even more inaccurate, and, with every care, some error will attend its adjustment to the parallel lines. Now, if to all these unavoidable sources of error, we add such as will attend a very acute intersection, primary stations so determined, from which other points in the sketch are afterwards to be derived, must lead to great incorrectness.*

Referring to the sketch before us, E, standing on an elevated knoll, is higher than any other of the stations ; and supposing the sketch extended beyond the limits here assigned to it, the point E, from its superior elevation, which enables us to look well around, ought to be carefully fixed. In this view, the lines A E and B E intersect too acutely for the degree of accuracy that is desirable, and ought therefore not to be solely trusted to ; especially as station D furnishes an opportunity to correct the position of E. When at D, therefore, the bearing of E is to be taken for this object.

* The student is not to be alarmed at this array of causes productive of error. In a sketch comprehending an area of a square mile, the most distant points will not be generally more than 30 or 40 paces out—a matter of little moment in a military sketch. But it was necessary to warn him on the subject.

Lastly, the bearing of F is observed from E, and the line C F is intersected, thus fixing F where the roads meet.

The contours of the hill should be sketched in during the foregoing operations. Thus, after protracting the bearings taken at A, the declivities near that station are sketched in, having reference to the lines laid down. In the direction of C, for instance, we find that at 140 paces a descent begins, and at 145 paces further we regain the summit—still walking direct upon C. When C is fixed, a curve is swept round to meet what was sketched from A, and thus the business proceeds.

With regard to the road in our sketch, we find three points on it laid down, namely, F, G, and the farm house: the intermediate portions of it are either sketched in by the eye alone, or bearings may be taken along it, to close from point to point—as from F, closing on G, and from G, on the farm.

If it were wished to carry the sketch over a greater extent of country, bearings to distant objects could be taken from points already fixed, as E, F, G, &c., and their several situations determined; and thus a net-work of triangles might be formed, similar to those of a trigonometrical survey. Indeed, our sketch is a minor description of trigonometrical survey. There is the base line A B. The primary stations, A, E, D, B, and C, with triangles formed by their bearings, laid down from each end of the base. Nothing can be more simple and easy than such an operation; and, notwithstanding the numerous sources of error above stated, a few square miles of country may be laid down in this manner with sufficient accuracy for every military purpose.

A scale should accompany each sketch, and a meridian line must be laid down.

PLATE IV.

Fig 1.

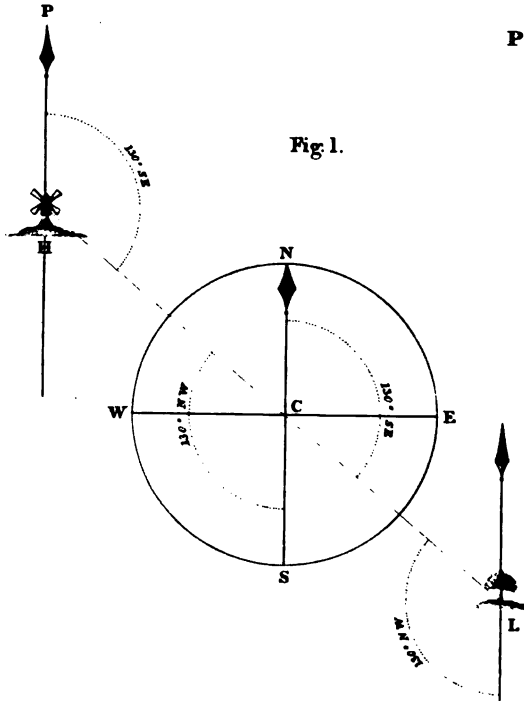
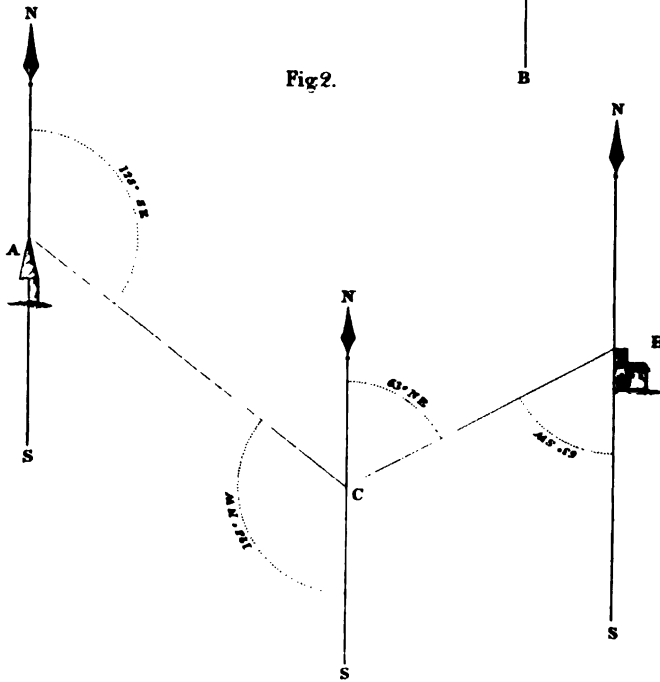


Fig 2.



**TO FIND YOUR PLACE IN A SURVEY OR SKETCH BY MEANS
OF TWO BEARINGS.**

It is advisable in all kinds of surveying to have few original stations, and these as wide of each other as the nature of the country will allow. The primary points being accurately determined, such intermediate stations as become necessary when filling in, are readily obtained in a very simple manner, by taking the bearings of two stations previously fixed; which has been called finding your station by *interpolation*, and is a truly useful little problem, that I shall now endeavour to explain.

With respect to the division of the compass card, it will be remembered that I recommend its being divided into twice 180° , instead of carrying the numbers round from 0 to 360° ; the advantage of which will be again seen here.

Let the circle N E S W (plate IV., fig. 1) represent the compass, having a line, H L, passing through its centre: the circle being divided into twice 180° , that is, the semicircle N E S is numbered from 0 to 180° , beginning at N; and the other semicircle S W N is numbered in like manner from S. Now, according to this mode of dividing the compass card, the bearing of the object H from C is 130° W., while that of the object L, from the same point C, is 130° E.: H C L being a straight line. Or it may be expressed thus, N S and H L being two right lines, cutting each other at C, the opposite angles are equal, namely, the angle H C S is equal to the angle N C L.

Again, Let P H and B L be parallel to the meridian N S; these lines then become the meridians* of the objects H

* Strictly speaking, meridians are not parallel, but they may be considered as such for surveying purposes.

and L respectively; and PH being parallel to BL, the alternate angles PHC and BLC are equal. Hence, if the bearing of the object H taken at L be 130° W., the bearing of L taken at H will be 130° E.

For the application of the above to our immediate purpose, namely, to find the place of a third station, by means of two stations already laid down on the paper:—

Let A and B (plate IV., fig. 2) be two stations, whose places are fixed, and we want to determine the point C. Take the bearing of A, 128° W.: having done which, we know, from the foregoing explanation, that C bears from A, 128° E. Adjust the protractor at A, by means of the east and west parallel lines, and lay off 128° E., the bearing of C; which point C must, we know, lie somewhere in the line thus obtained. Next, take the bearing of B, 63° E., and having adjusted the protractor at B, lay off 63° W. and where a line drawn from B (to represent this bearing) cuts the line or bearing drawn from A, is the required station C.

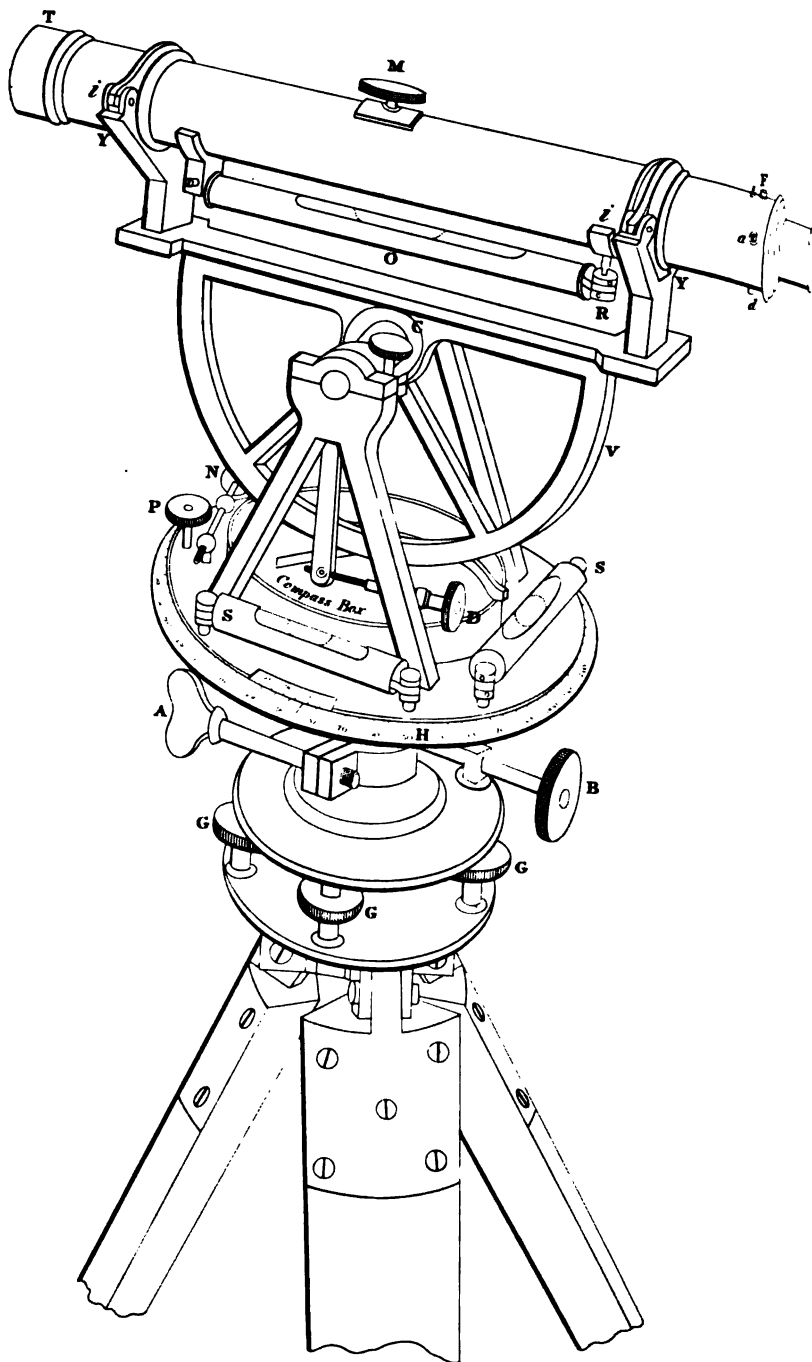
The above may be put into a short rule; thus—To find your station by observations taken to two points already known, protract *from those points* the *opposite* bearings to what you observe, and their intersection fixes the place sought. For example, if the bearing to a point be 20° E., protract from that point 20° W., &c.

Observe, that the nearer your two bearings meet at a right angle, the more correct will the station be determined: and also, that when a third fixed point can be seen, a bearing to it will serve to corroborate your other observations; and a point so obtained, namely, by the exact meeting of three bearings, becomes as good as any other point.

The above is a very useful problem—indeed, indispensable when sketching ground and filling in a survey.



PLATE V.



ON SURVEYING WITH THE THEODOLITE.

SECTION IV.

A DESCRIPTION OF THE THEODOLITE, AND ITS ADJUSTMENT IN THE FIELD. — TAKING ANGLES. — VERNIER SCALE.—ROAD SURVEYING WITH THE THEODOLITE AND CHAIN. — FIRST METHOD, BY THE COMPASS, OF THE THEODOLITE.—TO LAY DOWN OR PLOT THE SURVEY.—SECOND METHOD OF SURVEYING A ROAD, OR TRAVERSING WITHOUT THE COMPASS.—EXAMPLE OF TRAVERSING. — FURTHER DESCRIPTION OF THE THEODOLITE, WITH AN EXPLANATION OF ITS SEVERAL ADJUSTMENTS. — GENERAL OBSERVATIONS ON SURVEYING.

THE student who has carefully studied what is contained in the preceding sections, must have acquired considerable knowledge of surveying; and he will find the principles of the art are the same, whatever may be the extent of work to be performed, or the kind of instrument used.

The Theodolite (plate V.) is the most perfect instrument used in surveying, as it gives the horizontal angles without reduction.* It is composed of a telescope, T F; with a spirit level, O, attached. A vertical arc, V, for measuring angles of elevation and depression. A plate, termed the horizontal circle, H, having upon it cross spirit levels, S S. A compass. Parallel plates, with four vertical screws, G,

* An explanation of the difference between angles taken with a theodolite or compass, and those measured with a sextant, or other reflecting instrument, will be found in treating of the pocket sextant.

for levelling the horizontal circle. A clamping screw, A, to prevent the horizontal circle from moving round. A tangent or micrometer screw, B, to turn the instrument slightly, after being clamped by the screw A. A screw, P, for fixing the upper or index plate to the horizontal circle, H, which may then be slightly turned for a nice adjustment of the telescope to an object, by means of the micrometer screw, N. The instrument is mounted on three stout legs.

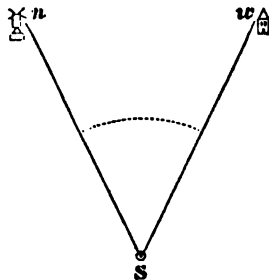
When in perfect adjustment, the horizontal circle is truly level. The vertical arc is in a plane, perpendicular to the horizon. The line of sight, or of collimation (*i. e.*, axis of the telescope), must be true, and the level attached to the telescope must be parallel to the line of collimation.

The theodolite is set up thus:—Place it over the station mark, spread the legs to about three feet apart, and move them until the *vertex* of the legs is exactly over the mark. A small stone dropped, or a plummet suspended from a hook, immediately under the vertex, will indicate when this is effected. Being satisfied as to the position of the instrument, press the legs firmly into the ground, and proceed to level it. Two spirit levels are generally fixed to the upper plate of the instrument, at right angles to each other. The four parallel plate screws, G, act upon this plate. Bring one of the spirit levels into a position parallel, if I may say so, with two of those screws that stand opposite or diagonally to each other. Now, by raising one screw, and lowering at the same time its opposite, the position of the horizontal circle will be changed. Continue working these screws until the bubble of the spirit level acted upon, rests in the middle of the open space: then work the other pair of screws, until a similar effect is produced upon the other spirit level. The adjust-

ment of the latter will, however, throw the other level somewhat out, rendering a return to it necessary. The horizontal circle is not truly level, or parallel to the horizon, until the bubbles of both spirit levels stand in the middle of the open spaces during a revolution of the instrument.

I have been particular in describing the above mode of levelling by means of vertical screws, because it is the principle commonly applied to theodolites; but I strongly recommend that all instruments should be levelled according to a method, introduced within the last few years by, I believe, Mr. Gilbert. The improved manner of levelling is by means of two horizontal screws acting upon the *spindle* of the instrument, in its socket; which action of the screws is resisted by two spiral springs. This I consider to be a very great improvement upon the old method of levelling; and having had a theodolite so improved in use for some time, I can speak of its merits from experience. It causes a great saving of time and trouble.

An angle is measured with the theodolite, thus:—



S is the station of the instrument: required the angle between the windmill, *n*, and the spire, *w*. Plant the theodolite over the station point, as directed above, carefully attending to all the instructions just given. Make zero of the vernier scale to coincide with zero of the hori-

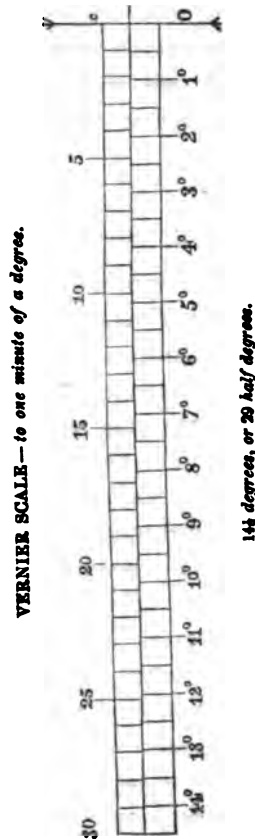
zontal circle, and fix them so by tightening the screw, P. Place the intersection of the hairs in the telescope on the windmill, *n*, and fasten the clamping screw, A; then, if the object, *n*, is not found to be exactly covered by the point where the hairs cross each other, turn the micrometer screw, B, which will enable you to fix it with the utmost precision. This effected, loosen the screw, P, which will release the index, or vernier plate from the horizontal circle; then turn the upper part of the instrument until the cross hairs cut the object, *w*. The vernier micrometer screw, N, enables this to be done very exactly, on tightening the screw, P. Then the number of degrees and minutes passed over by the vernier, or index, shows the measure of the angle.

VERNIER SCALE.

The vernier scale, which is applied to instruments both for measuring angles and distances when great accuracy is required, must now be noticed. The horizontal circles of ordinary theodolites are divided to half degrees, and are most convenient when numbered from zero to 180° , as recommended for the prismatic compass. Now, without such a contrivance as the vernier, we can only guess at the number of minutes, when the index does not exactly agree with one of the subdivisions; but, by means of a vernier, we are enabled to read off an angle on the circle of an ordinary theodolite to a single minute; and may, if the horizontal circle be very large, read off to twenty seconds with the greatest certainty.

The construction of this ingenious contrivance is simple. Suppose we want to read off to one minute. — Take the length of 29 half degrees on the horizontal circle, and divide that distance into 30 equal parts; this forms the vernier, which is marked for convenience, 5, 10, 15, 20,

25, 30, from one end, or the zero. Place the vernier to the horizontal circle, so that zero of the former may be in contact with zero of the circle; then the last division, marked 30, of the vernier will, of course, agree with $14\frac{1}{2}$ degrees, or 29 half degrees of the circle: and the proportion



of each division of the vernier will be to a division of the circle, as 29 to 30. If the zero of the vernier be moved from the zero of the circle, then the first coincidence that takes place between a division of the vernier with one on the circle, indicates the number of minutes passed over.

To read off an angle on the horizontal circle, use a magnifying glass, and notice how many degrees have been passed over by the zero of the vernier : for example, let us suppose that the arrow at zero of the vernier has passed the 21st degree of the circle ; then, for the number of minutes in addition, look along the vernier, until one of its divisions is found to agree exactly with a division on the circle below it. You find, we will suppose, that the 14th division of the vernier does so : then the angle is $21^{\circ} 14'$.

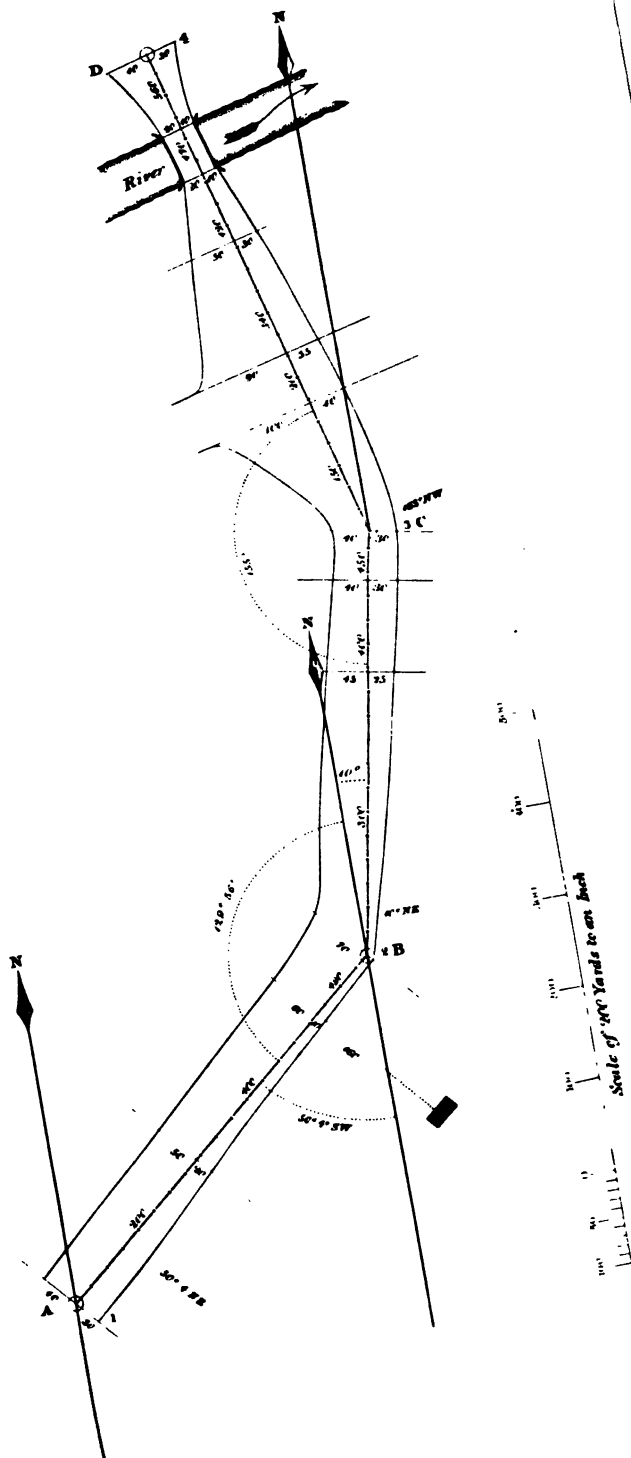
ROAD SURVEYING WITH THE THEODOLITE AND CHAIN.

Formerly, surveyors made much use of the compass which is attached to the theodolite, when engaged in surveying roads, rivers, boundaries, and performing such work as is now generally termed *traversing* ; this mode is similar in principle to that of surveying with a prismatic compass, as described in Section III., but more accurate, owing to the superiority of the theodolite. The needle, however, cannot always be depended upon ; as, besides being affected by local attraction,* it is subject to a trifling variation at different times of the day. This imperfection in the needle has induced most surveyors to abandon the expeditious mode of working by it, when using the theodolite ; they now generally practise a method which leaves them independent of the compass, save to note the cardinal direction of their station lines. Both methods shall be described.

The following implements are required for the survey of a road :—

* One of my brother officers lost a whole day's work, at a very important period of the Peninsular war, in consequence of iron ore being abundant on the banks of the Zézere river. When he came to plot his numerous bearings, taken during a busy day, nothing could be made of the work.

PLATE VI.



A measuring chain.

Ten arrows.

Two staves, for placing as marks at the stations.

A field-book, for registering the observations and measurements.

I have already said that land surveyors commonly use the Gunter chain, of 66 feet, divided into 100 links; which is very convenient when the contents of an estate or parish are to be given in acres, roods, &c.: but for our purpose, a chain 100 feet long is to be preferred, the object being to obtain lineal, and not superficial measure. The 100 feet chain is divided into links of one foot each; and certain brass marks, fixed on it at ten feet distance from each other, show at once any number of feet less than 100.

FIRST METHOD OF SURVEYING A ROAD WITH THE THEODOLITE.

Let A (plate VI.) be the point upon a road for commencing a survey with the theodolite and by the needle. Set up the instrument very exactly over the point marked, level it carefully in the manner already described, and place zero of the vernier to agree with zero of the horizontal circle; then, by means of the screw, P, fix the two plates together. Now turn the instrument on its axis, until the marked end of the needle settles exactly at the division in the compass box at N, or north, marked 360 or 180, and tighten the clamping screw, A; then, if the needle does not accurately agree with the 360 or 180 (as the case may be, for theodolites are differently numbered,) in the compass box, use the micrometer or tangent screw, B, which will adjust it to the greatest nicety. All is now ready to take a bearing.

Place a staff or bandrol at the point B,* where the road makes a bend, and examine your instrument again to see, 1st, that the index or zero of the vernier corresponds with zero of the horizontal circle; 2nd, that this circle is truly level; 3rd, that the needle points exactly to the division at N; and, lastly, that the clamping screw is firm.

To take the bearing of the staff planted at B, loosen the screw, P, which connects the vernier plate with the horizontal circle, and turn the vernier plate, with the upper portion of the theodolite, on its axis; continue this until the staff at B is seen through the telescope: then tighten P, and turn the micrometer screw, N, at the same time, raising or depressing the telescope as much as may be requisite. Fix the intersection of the hairs in the telescope precisely on the *bottom* of the staff at B. The divisions in the compass box will indicate how many degrees have passed the *stationary* needle; but we must refer to the vernier for the exact measure of the angle, that a line from A to B forms with the meridian, which meridian is represented by the direction of the needle. On examination, we find that the zero of the vernier is something past the 50th degree of the circle; and looking along the vernier, through the magnifying glass, it appears that the 4th division on it agrees with a division of the circle. Thus, the bearing is $50^{\circ} 4'$; and as we perceive, looking at the needle, that $\odot$ B lies to the right, or eastward of north, we put down $50^{\circ} 4' \text{ N.E.}, \odot$; the latter mark being to distinguish the station angle or bearing, as the case may be, from any other angle or bearing that may be observed at the same time. The first entry in the field-book is

* The letters A, B, &c., are not necessary in surveying, to mark the stations on a road; $\odot$ 1, $\odot$ 2, &c., is sufficient for that purpose. Letters are used here to facilitate the descriptions.

Form of Register
or
FIELD BOOK.

	40	560	30	
	20	470	10	
River	20	420	10	
	50	340	30	
	90	210	35	
From	100	150	40	
		165° N.W.		
		⊙ 3		C
	40	450	30	
	40	400	30	
	45	300	25	
		10° N.E.		
		⊙ 2		B
	70	480	6	
	60	400	10	160
	50	200	20	
		50° 4' N.E.		
	40	⊙ 1	30	A

Began at Mile stone going towards

made at the bottom of the page, proceeding upwards. (See the specimen of a field-book, (plate VII.)

The next step is to measure the distance from A to B. To do this, an assistant takes one end of the chain, and proceeds towards B, until desired to stop by the person holding the other end. The latter places himself over the point where the instrument stood, and motions the chain leader, who is facing him, to move right or left, until he is exactly in a line with a staff at B. The chain is then drawn tight, and left on the ground while any off-sets, that may be necessary, are taken. Off-sets, it will be remembered, are measurements laterally from the chain, and usually perpendicular to it, to determine the distance of a house, fence, gate, &c., from the chain line. For instance, the breadth of the road at A (plate VI.) is found by measuring, or taking an off-set at right angles with the chain line to the fences, on each side of that point, namely, to the right, 30 feet, and to the left, 40; which are entered in the field-book at A. Off-set measurements may be made by pacing, with a wooden rod, or a measuring tape, according to the degree of accuracy required. Pacing does very well for military plans, and the eye is a sufficient guide for the direction, so as to go perpendicularly to the chain line.

Let me remind the student, that the space between the two ruled lines of the field-book represents the chain. Bearings or angles taken during the survey, together with all distances measured between stations, are entered in this space; but all off-sets from the chain, are put down outside the ruled lines.

To proceed with the measurement towards B. The chain leader has ten arrows, one of which he sticks into the ground at the end of the chain, or makes a cross if the road is hard, and lays the arrow down: he then draws

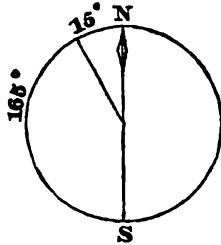
the chain forward, giving it a cast to the right, so as to keep it from disturbing the arrow he has placed. When the chain follower comes within a few feet of the arrow placed at the end of the first chain, he calls "Halt," places the leader in line with B, and takes up the arrow. At two chains, or 200 feet, from A, a second off-set is taken, namely, 20 feet on the right, and 50 feet on the left; which are entered, as seen in the field-book. Thus the measurement proceeds as fully described at page 41.

At 400 feet, there is an off-set to a house standing at the distance of 160 feet from the chain. Be it observed, that all off-sets are to be put down at their distance from the chain: here, for example, we have ten feet to the fence, and 150 from thence to the house; but we enter 160, the distance of the house from the chain.

When the measurement of the first station is completed, the theodolite is set up at $\odot 2$ (B), care being taken to place it vertically over the hole in which the staff stood, which may be ascertained by dropping a stone from the vertex of the legs of the instrument, or by a plummet, as already mentioned. A staff is to be planted at the next bend of the road, C, and the instrument adjusted; when the bearing of C, or $\odot 3$, is to be taken, and the chaining proceeds as before.

When observing at $\odot 3$ (C), $\odot 4$ (D) is found to bear west of the meridian. It will be recollected that when using the surveying compass, all bearings lying on the west side of the meridian were reckoned from the *south* pole of the needle, round towards west and north; and the same method had better be adhered to still. The horizontal circle of a theodolite is commonly divided in the manner recommended for the surveying compass, namely, into twice 180° , and the circumference of its compass box in the same way to correspond. However, the learner

will find that it does not signify, whether the bearing of D, in this instance, be entered as 15° N.W., or 165° N.W.; the same line must be produced in plotting, whichever way the bearing has been put down; for a bearing always



being taken from the meridian, 15° N.W. can only be plotted from N., while 165° N.W., must necessarily be taken from S. A little consideration will make this quite clear to the student, who will in practice follow *one* method of entering bearings, adopted according to the manner in which the circle of his instrument may be divided. Some circles being numbered (as already observed) from 0 to 180° , and others from 0 to 360° .

But returning to the survey.—Previous to our arriving at D ($\odot$ 4), a bridge is passed, when, if an off-set be taken at each margin of the stream, its width is determined.

The student, who understands what has been said thus far, will readily perceive that he has no need to set the instrument up at every station: thus, instead of taking the bearing of B from A, he may at once proceed to B, and taking the bearing of A, which is here $50^{\circ} 4'$ S.W., he enters at $\odot$ 1 in the field-book as $50^{\circ} 4'$ N.E., being the alternate angle, or *opposite bearing*. The bearing of C is then taken, and entered in the field-book as before. After which the instrument is removed to D, from whence the bearing of C is taken, and so on.

Enough has now been said as a guide for acquiring the

method of surveying a road by the needle: I shall, therefore, merely observe in addition, that when a very exact survey is required, the kinds of fencing are noted, and gates, trees, &c., are to be put in. For these, and various other objects noticed in a plan, certain conventional signs are used, which will be detailed when plan drawing is treated of, to which branch they properly belong.

TO LAY DOWN OR PLOT THE ABOVE SURVEY UPON PAPER.

It will readily be perceived, that bearings taken accurately to minutes of a degree with a theodolite, will avail us little, unless we have likewise the means of plotting them with equal accuracy. This we are enabled to do by means of a protractor, furnished with a vernier, of a circular or semicircular form. We will suppose the learner to be provided with one of the latter shape.

Draw a line, N S, upon the paper, to represent the meridian of A (see plate VI.); mark a point upon it for $\odot 1$, A. Apply the protractor so as for its base or diameter to lie along the meridian line, having its centre at the station point, and set the vernier to the first bearing entered in the field-book, namely, $50^{\circ} 4'$; or this may be done previous to placing the protractor: draw a fine line on the paper along the arm of the protractor from $\odot 1$, which line defines the direction of $\odot 2$, B, lying $50^{\circ} 4'$ N.E. of the meridian. Next, from any scale of equal parts selected for the survey, take in the compasses 480, being the whole length measured to B; * this distance taken along the line just drawn, fixes $\odot 2$, B. Through this

* A good method is to divide a slip of paper very accurately according to the intended scale, and apply it to the chain line; this is an expeditious mode, but not quite so exact as that of taking distances from an ivory *diagonal* scale with a pair of fine compasses.

point, draw a line, NB , parallel to NAS , for the meridian of $\odot 2$. After which, set the protractor to 10° , apply it to the line NB , and lay off BC . Take 450 from the scale, and fix the point C , $\odot 3$. Thus continue until all the stations are laid down. When satisfied that these are correctly fixed, the off-sets are to be plotted: here a slip of paper divided according to the scale is extremely useful. First, mark a point at 200, and another at 400 feet from $\odot 1$. Turn the slip of paper at right angles to the line AB , and at the point A set off 40 and 30, as seen in the plan: then at 200 feet, again use the slip scale, and mark 50 on the left, and 20 on the right: at 400 feet, 60 and 10. Join these points of the cross measurements, or off-sets, and the boundaries of the road will be correctly shown.

The road given in plate VI., being accurately drawn to a scale of half an inch to 100 feet, namely, the large diagonal scale on the ivory protractor—a comparison of it with the description given, will, it is hoped, render the whole process perfectly intelligible.

SECOND METHOD OF SURVEYING A ROAD, OR TRAVERSING,
WITHOUT THE COMPASS.

Having planted the theodolite at the point from whence it is intended to begin a survey, and the several adjustments having been made, set the vernier at zero, or 180° (the horizontal circle being divided into twice 180°), and clamp the vernier plate; then turn the instrument until the magnetic needle agrees with the N . and S . points of the compass. Let the point A (plate VI.) represent the station of our instrument, AN the meridian of that point, and B a bandrol, where the road makes a turn. The angle,

N A B, being measured, is found to be $50^{\circ} 4' \text{ N. E.}$ *Keep the vernier clamped at that angle*, remove the theodolite to B, and, without unclamping, direct the telescope on a bandrol fixed at A; this effected, and keeping the instrument firmly clamped by the screw A (plate V.), loosen the vernier plate, and adjust the telescope on a bandrol at C, the third station; the reading off will then be 10° ; for, previous to unclamping the vernier plate, the reading was $50^{\circ} 4'$, and $129^{\circ} 56'$ completed the 180° : the new reading off is therefore the amount of the angle N B C, or 10° . Clamp that angle, remove the theodolite to C, and adjust the telescope on B; then release the vernier plate, and direct the telescope on D, when the reading will be 165° , viz., 155° added to the 10° ; and so the survey proceeds.

It will be perceived that, after the adjustment of the needle at the first station, it becomes no longer necessary, except to point out the directions of the several station lines; and hence this method has a great superiority over that of surveying by the needle. But the advantage does not end here, for we have no occasion to make use of the magnetic meridian from which to measure our angles; any line will do equally well; so that, when filling in a survey, it is usual to select some fixed and conspicuous point, from which to measure the first angle. The several station lines of the road survey have then reference to an assumed working meridian, viz., the line between our first station on the road and the conspicuous object chosen; and the compass is only used to denote the directions of our station lines, rendering us independent of all local attraction; which, as I have already remarked, sometimes very materially affects the needle.

In surveying a road, any remarkable object that may be visible from several stations, and not more than from half

to three-quarters of a mile distant, that the intersections may not be too acute, should have its bearing frequently taken as a check upon the work; for afterwards, in plotting, when the several bearings to an object unite at a point, the proof of accuracy is complete and satisfactory: indeed, some such check is at all times necessary. When any check-bearings are taken, it is usual to enter them in the field-book before the forward or station bearing, to avoid mistake; but it is better to place this mark (⊙) at all times against the bearing, or angle, which gives the direction of the road or the line on which you measure.

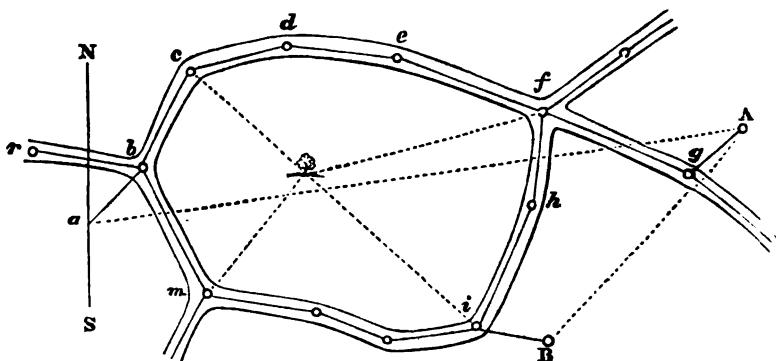
In order to be able to resume an incomplete survey, a mark must be made at the last station by cutting a cross in the sod, or driving a strong peg into the ground. And it is necessary, both on beginning and ending a day's work, to take angles between the back or forward stations and any two fixed points that may be visible.

EXAMPLE OF TRAVERSING.

The following example is taken from Mr. Simms's treatise on instruments; and I recommend it to the student's attention, as highly useful in showing how a check is maintained over a road survey, so as to preclude a possibility of error.

Let the diagram in the next page represent a survey of roads to be performed with a theodolite and chain. Commencing on a conspicuous spot, *a*, near the place where two roads meet, the theodolite must be set up and levelled, the upper and lower horizontal plates clamped at zero, and the whole instrument turned about until the magnetic needle steadily points to the NS line of the compass-box, and then fixed in that position by tightening the clamping screw A (see plate V.). Now release the upper plate, and

direct the telescope to any distant conspicuous object within or near the limits of the survey, such as a pole purposely erected in an accessible situation ; that it may be measured to, and the instrument placed upon the same spot at a subsequent part of the operation, as A and B, and after bisecting it with the cross wires, read both the verniers of the horizontal circle, and enter the two readings in the field-book ; likewise, in the same manner, take bearings, or angles, to all such remarkable objects as are likely to be



seen from other stations, as the tree situated on a hill ; and lastly, take the angle to your forward station, *b*, where an assistant must hold a staff for the purpose, on a picket driven into the ground,* in such a situation as will enable you to take the longest possible sight down each of the roads that meet there. In going through the above process, at this and every subsequent station, great caution must be used to prevent the lower horizontal plate from having the least motion after being clamped in its position by the screw A.

* A picket should always be left in the ground at every station, in order to recognise the precise spot, should it afterwards be found necessary to return to it again.

Next measure the distance from a to b , and set up the instrument at b ; release the clamp-screw *A only*, not suffering the upper plate to be in the least disturbed from the reading it had when directed at a to the forward station b ; with the instrument reading this forward angle, turn it bodily round, till the telescope is directed to the station a (which is now the back station), where an assistant must hold a staff, tighten the clamp-screw *A*, and by the slow-motion screw *B*, bisect the staff as near the ground as possible, and, having examined the reading, to see that no disturbance has taken place, release the upper plate, and, setting it at zero, see if the magnetic needle coincides, as in the first instance, with the *NS* line of the compass-box; if it does, all is right, if not, an error must have been committed in taking the last forward angle, or else the upper plate must have moved from its position before the back station had been bisected; when this is the case, it is necessary to return and examine the work at the last station. If this is done every time the instrument is set up, a constant check is kept upon the progress of the work; and this indeed is the most important use of the compass. Having thus proved the accuracy of the last forward angle, release the upper plate, and measure the angles to the stations m and r , and, as before, to whatever objects you may consider will be conspicuous from other places; and lastly, observe the forward angle to the station c , where the theodolite must next set up, and measure the distance $b c$.

At c , and at every succeeding station, a similar operation must be performed, bisecting the back station with the instrument reading the last forward angle; then take bearings to every conspicuous object, as the tree on the hill, the station *A*, &c., which will fix their relative situations on the plan, and they afterwards serve as fixed points to prove

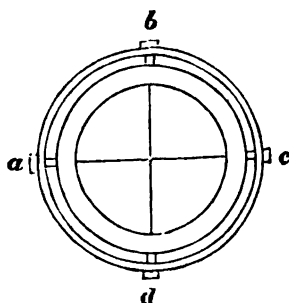
the accuracy of the position of such other stations as may have bearings taken from *them* to the same object; for, if the relative situations of such stations are not correctly determined, these bearings will not all intersect in the same point on the plan. The last operation at each station is to measure the forward angle. In this manner proceed to the stations *d, e, f, g, &c.*, and having arrived at *g*, measure the angle to the pole *A*, as to a forward station, and, placing the theodolite upon that spot, direct the telescope to *g*, as a back station, in the usual way; this done, release the upper plate, and direct the telescope to the *first* station *a*, from which *A* had been observed, and if all the intervening angles have been correctly taken, the reading of the two verniers will be precisely the same as when directed to *A* from the station *a*; this is called *closing* the work, and is a test of its accuracy, so far as the angles are concerned, independent of the compass needle. If the relative situation of the conspicuous points, *A, B, &c.*, were previously fixed, there would be no necessity to have recourse to the magnetic meridian at all, as a line connecting the starting point *a*, with any visible *fixed* object, may be assumed as a working meridian; and, if it be thought necessary, the reading of the compass needle may be noted at *a*, when such fixed object is bisected; and upon the theodolite being set to the reading of this assumed meridian, at any subsequent station, the compass needle will also point to the same reading as it did at first, if the work is all correct, and no local attraction influences the compass.

While the instrument is at *A*, take angles to all the conspicuous objects, particularly to such as you may hereafter be able to close upon, which will (as in the above instance) verify the accuracy of the intervening observations; having done this, return to *g* and *f, &c.*, and pro-

ceed with the survey in the same manner as before, setting the instrument up at each bend in the road, and taking off-sets to the right and left of the station lines; arriving at *i*, survey up to, and close upon, B; then return to *i*, and proceed from station to station till you arrive at *m*, where, if the whole work is accurate, the forward angle taken to *b* will be the same as was formerly taken from *b* to *m*, which will finish the operation.

FURTHER DESCRIPTION OF THE THEODOLITE, WITH AN
EXPLANATION OF ITS SEVERAL ADJUSTMENTS.

The *telescope* should be of the achromatic kind, in order to obtain a larger field and a greater degree of magnifying power. In the focus of the eye-glass are two hairs at right angles to each other: they are of spiders' thread, and attached by means of a little gum to a circular brass ring, smaller than the tube of the telescope. In this figure the outer circle represents a section of the tube of the telescope; the inner, a brass ring to which the threads are attached, fixed to the tube by the four small screws *a*, *b*, *c*, *d*, near



the eye-end of the telescope. If the screw at *a* be eased, while at the same time that at *c* is tightened, the ring will be moved to the right; and in the same way it may be

moved up or down by turning the screws at *b* and *d*. The object of this contrivance is to place the intersecting point of the threads in the centre of the telescope—its axis.

The object-glass of the telescope is moved by means of a milled nut, *M*, in order to suit the eye of the observer, and his distance from the object. The telescope rests on supports, called *Ys*, which are fixed to the vertical arc, and so formed as to be *tangents* to the cylindrical rings encircling the tube of the telescope, and consequently the *bearing* is only upon two points in each *Y*. (Plate V.)

The vertical arc, *V*, is graduated on one side to half degrees, and provided with a vernier reading to one minute. It is numbered each way from 0 to 45° or 50°, for taking angles of altitude or depression. On the other side of the vertical arc, a range of divisions is sometimes given for reducing hypotenusal lines to horizontal ones, or showing the difference between the hypotenuse and base of a right-angled triangle, always supposing the hypotenuse to consist of 100 equal parts; therefore, the number of feet to be deducted from each chain's length in measuring up or down a slope, in order to reduce it to the true horizontal distance, is seen at once.

The horizontal circle, *H*, consists of two plates, one moveable on the other. The upper, or index-plate, carries a vernier scale adjusted to the divisions of degrees and half degrees of the lower plate. The index-plate (together with the compass, vertical arc, and telescope,) turns on its axis independent of the lower plate; which latter turns on the same axis, but is fixed in any position by tightening the clamping-screw, *A*. The screw, *P*, fastens the two plates together, when the upper plate may be made to move a short distance by turning the tangent-screw, *N*. The horizontal circle is divided into half degrees, and numbered from 0 to 360° or 180°. The

vernier scale subdivides the half degrees to one minute or less, according to the size of the instrument.

The compass is fixed on the upper plate. It is divided to 360° , numbered contrary to the horizontal circle. The letters E and W are generally transposed; the use of which is that, in taking a bearing, 50° west for instance, the needle remaining stationary shows 50° towards W, or west. But with the letters properly placed, the needle would point to 50° between the N and E points.

THE ADJUSTMENTS OF THE THEODOLITE.

Every one using the instrument ought to be able to adjust it for himself. The first adjustment is that of the line of sight, or of collimation, as it is termed; which is to place the intersection of the cross hairs exactly in the centre or axis of the cylindrical rings of the telescope resting on the Ys. To effect this, place the theodolite on its legs, and direct the telescope so that the centre of the horizontal hair shall coincide with some well-defined part of a distant object; then turn the telescope in the Ys, till the level is uppermost; observe then whether the horizontal hair still coincides with the object, if so, the hair is in its right position; if it do not so coincide, correct *half* the difference by moving the hair, which motion is effected by easing one of the hair-screws, *a*, *b*, *c*, and *d*, and tightening its opposite; after which, turn the telescope in the Ys till the level tube is underneath, and make the horizontal hair coincide with the object, by moving the vertical arc, V; again turn the telescope till the level is uppermost, and if the hair do not cut the same part of the object, the above operation must be repeated till, in both positions of the telescope, the horizontal hair cuts the same part of the distant object. The horizontal hair being thus adjusted,

turn the telescope until the other hair is placed in an horizontal position, and proceed as before. When the two hairs are thus adjusted, their point of intersection will coincide exactly with the same point of the distant object while the telescope is turned round; and the hairs are not properly adjusted till this is effected.

The second adjustment is that which puts the level attached to the telescope parallel to the rectified line of collimation. The clips, *ii*, being open, and the vertical arc clamped by turning the screw, C, bring the air-bubble of the level to the centre of its glass tube, by turning the tangent-screw, D, which gives a slow motion to the vertical arc; this done, reverse the telescope in its Ys, that is, turn it end for end, which must be done carefully that it may not disturb the vertical arc, and if the bubble resume its former situation, in the middle of the tube, all is right; but if it retire to one end, bring it back one half by the screw, R, which elevates or depresses that end of the level, and the other half by the tangent-screw, D, of the vertical arc: this process must be repeated until the adjustment is perfect.

The third adjustment is that which makes the azimuthal axis, or axis of the horizontal circle, truly vertical.

Set the instrument as nearly level as can be done by the eye, fasten the centre of the lower horizontal plate by the clamping-screw, A, leaving the upper plate at liberty, but move it till the telescope is over two of the parallel plate-screws; then bring the bubble of the level under the telescope to the middle of the tube, by the screw, D; now turn the upper plate half round, that is, 180° from its former position; then, if the bubble return to the middle, the plate is horizontal in that direction; but if otherwise, half the difference must be corrected by the parallel plate-screws, over which the telescope lies, and half by elevating

or depressing the telescope, by turning the tangent-screw, D, of the vertical arc: having done which, it only remains to turn the upper plate forward or backward 90° , that the telescope may lie over the other two parallel plate-screws, and, by their motion, set it horizontal. Having now levelled the horizontal circle, by means of the telescope level, which is the most sensible upon the instrument, the other air-bubbles fixed upon the vernier plate, may be brought to the middle of their tubes, by merely giving motion to the capstan-headed screws at each end of them.

The vernier of the vertical arc may now be attended to: it is correct, if it points to zero, when all the foregoing adjustments are perfect; and any deviation in it is easily rectified, by releasing the screws by which it is held, and tightening them again after having made the adjustment; or, what is perhaps better, note the quantity of deviation as an index error, and apply it, plus or minus, to each vertical angle observed. This deviation is best determined by repeating the observation of an altitude or depression in the reversed positions, both of the telescope and the vernier plate: the two readings will have equal and opposite errors, one half of the difference being the index error. Such a method of observing angles is decidedly the best, since the mean of any equal number of observations, taken with the telescope reversed in its Ys, must be free from the effects of any error that may exist in the adjustment of the vernier or zero of altitude.

It is of great importance that the telescope and vertical arc should move in the same vertical plane: in small theodolites, this is provided for by the construction, and no means are afforded for making any alteration; but larger instruments are furnished with screws for this adjustment. To prove the accuracy of the vertical arc, suspend a weight by a long plumb line from a branch of a tree, or otherwise,

and adjust the cross hairs upon it; then, by means of the elevating screw, cause the vertical arc to rise, and observe whether the cross hairs continue on the line while the vertical motion continues. Or fix them on the angle of a lofty building, and raise or depress the telescope, when the cross hairs will continue to move on the angular line, if the adjustment be perfect. For depression, a reflection of the same angle of a building from an artificial horizon, will serve as a test.

GENERAL OBSERVATIONS ON SURVEYING.

Surveying may be defined, the art of representing a country, or any portion of the earth's surface, upon paper, in such a manner that we may be able, by means of a scale, to measure the horizontal dimensions of its features; as territorial boundaries, lakes, rivers, forests, roads, &c.

“ Accurate surveys of a country are universally admitted to be works of great public utility, as affording the surest foundation for almost every kind of internal improvement in time of peace, and the best means of forming judicious plans of defence against the invasions of an enemy in time of war; in which last circumstance, their importance usually becomes the most apparent. Hence, it happens, that if a country has not actually been surveyed, or is but little known, a state of warfare generally produces the first improvements in its geography: for in the various movements of armies in the field, especially if the theatre of war be extensive, each individual officer has repeated opportunities of contributing, according to his situation, more or less towards its perfection; and these observations being ultimately collected, a map is sent forth into the world, considerably improved indeed; but which being still defective, points out the necessity of something more

accurate being undertaken, when times and circumstances may favour the design."—*Introduction to an Account of the Trigonometrical Survey of England.*

The foundation of every survey is a base line; and upon the accuracy with which the length of the base is obtained, the correctness of the entire survey must depend.* The measurement of a base, then, is not only the primary, but also the most important work to be performed. Various methods have been pursued to effect this object.

Previous to the measurement of the Hounslow base, deal rods were considered very good for the purpose, and had been extensively used on the Continent; but experiments made on that occasion proved their unfitness, owing to the uncertainty of their expansion; perhaps, however, our more humid climate may have produced a greater effect upon them, than the comparatively dry atmosphere where they had before been tried; and it appears, from the account of the operations on Hounslow Heath, in 1784, that the season was a very wet one. On the whole, if I may presume to offer an opinion in the matter after their condemnation by men of so much science, I should still

* The length of the base measured on Hounslow Heath, for the grand Trigonometrical Survey of England, in 1784, was, when reduced to the level of the sea, 27404·1037 feet. Three modes of measuring were tried, viz., with deal rods, with a steel chain of peculiar construction, and by means of glass tubes. The uncertain expansion and contraction of the deal rods, was found to produce a very fallacious result. The steel chain does not appear to have had a fair trial upon this occasion. The method proposed with glass tubes obtained the preference. Accordingly, the measurement took place with these, and was conducted in a scientific manner, with all the care due to so important an operation. In 1791, a careful measurement of the same base was made with the improved steel chain, which only differed from the original one performed with glass tubes, by about 2½ inches. Subsequently, in 1794, a base of verification was measured on Salisbury Plain, which varied only about 3½ inches from its computed length.

advise the use of deal rods under other circumstances, and where glass tubes and steel chains, such as were used on the occasion above mentioned, with all the vast preparation made for their application to the object in the most perfect manner, cannot be had; and, more than all, when the contemplated survey is not of the most important character.

Indeed, Mr. Dalby, the associate of General Mudge in the grand survey, recommends the use of such rods on ordinary occasions; and as I look upon that gentleman's opinion with respect, I shall quote from his work on Mathematics what he says on the subject, concurring, as I do, with his views, and not being aware of any better plan to substitute for the one he proposes.

“ But the most difficult, and tedious operation connected with a survey, is that of measuring a base-line accurately. We shall therefore recommend a perusal of the account of the *Trigonometrical Survey*, to those who may engage in an undertaking of this kind, when great exactness is required. A base for common surveys may be measured with a 20 feet deal rod: for this purpose, a rope, not less than 100 yards, should be stretched very tight along the ground; the rod must then be applied to the rope, and its extremity may be marked with a small pin stuck in the rope, to preserve the distance while the rod is removed. When the measurement is carried on to the extent of the rope, a peg should be driven in the ground, and a notch cut on its top, exactly under the end of the last rod. The rope must then be taken up, and stretched again in the direction of the base, and the measurement continued as before.

“ When the measurement is carried over hollows or ditches, it may be necessary to support the rod in the middle: it should not, however, be made very slender.

“ If rising grounds intervene, the slant distances must be measured as hypotenuses, and afterwards reduced to the corresponding horizontal lines: the elevations and depressions may be taken with a theodolite which has a vertical arc.

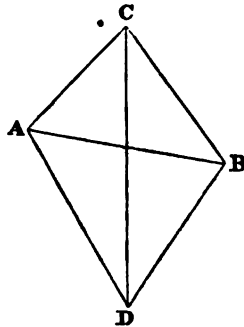
“ It may be necessary to observe, that 20 *feet* should be transferred to the rod from a *standard measure*. And with respect to expansion and contraction, it is pretty well known that well-seasoned deal is subject to very little alteration, while it is kept dry.

“ If a measurement of this kind be performed with tolerable care, we may safely conclude, there will not exist an error of more than one-tenth of an inch in each rod of 20 feet, or $26\frac{1}{4}$ inches in a mile. Supposing, however, the accumulated errors amount to five feet in a base of two miles, and that a series of triangles, whose sides are about three miles, to be determined from such a base—then combining the probable errors from observations made with a theodolite—the uncertainty, in a direct distance of 20 miles from the base, cannot amount to 30 yards. Erroneous as this may be considered, we believe most of the county maps have been laid down from operations less accurate.”

In ordinary surveys, it is not necessary to enter into calculations, on account of the sphericity of the globe; nor indeed into many other niceties, such as would be imperative, were the object to measure an arc of the meridian, or perform any other grand trigonometrical operation. On common occasions it suffices to consider the earth as a plane or flat surface, and all the sides of the triangles as right lines, instead of curves.

The ground having been selected for measuring a base, and this operation performed with all the accuracy the means will admit of, the next step is to choose the most

eligible points for carrying on the triangulation—a survey being conducted by means of a series of triangles, of which the base line forms one side of the first. With this view, conspicuous situations are fixed on, as the tops of hills, church towers, &c. These primary stations ought generally to be of a distance from each other, bearing some proportion to the length of the base and extent of the proposed survey. For instance, if the base be two miles, and extent of the survey 15 or 20 miles, the sides of the triangles may be from two to four miles; much, however, must always depend on the relative positions of commanding points for stations, and on the two first triangles of the survey. For example:—Suppose AB to represent a base line, and that C and D are eligible stations, forming two triangles, ACB



and ADB . Knowing the length AB , and the angles at A and B , the length of CD is found by an easy calculation in trigonometry; and that line becomes nearly as good a base in point of measurement, as AB , while it possesses the advantage of being longer, and thus enabling us to increase the sides of our triangles.*

* This method of obtaining a longer base, as it may be termed, becomes useful when a base is measured on low ground between hills, as must frequently be done; such situations being often level, and suitable for the purpose.

Wherever the instrument is set up, observations should be taken to all remarkable objects; these being repeatedly intersected, furnish a check on the work as it proceeds, and their several positions are furthermore determined for future use.

When possible, all the three angles of the principal triangles should be observed; then, as the sum of the three angles ought to be 180° , we are enabled to judge of the accuracy of the observations, and in some degree of the perfection of the instrument used.

The sides of all the principal triangles should be *calculated*, and laid down by means of beam compasses—as protraction by the *sides* is always more correct than by the *angles*. In triangles on a large scale, an error of a single minute, in protracting an angle, would sensibly affect the length of the sides.

As it is impossible to avoid some degree of error in taking angles, we should endeavour so to order our operations that the error may have the least possible influence on those sides, the exact measure of which is the object to be obtained.

When the base cannot be equal to the side or sides sought, it should be as long as possible; and the angles at the base should be nearly equal.

Sometimes it occurs that the three angles of a triangle cannot be observed; in that case, the angle obtained by intersection should be as near as possible a right one. Acute intersections are at all times to be avoided.

The fewer the principal stations, the less will be the labour of the survey; it will also be more accurate, and less liable to mistakes while in the field, or errors when plotting the work at home.

Military men generally fill in the principal triangles by means of the pocket sextant and surveying compass,

when the survey is not required to be minutely exact in all its details.

These general observations might be multiplied to an unlimited extent ; and yet, after all, when a survey is to be undertaken, the surveyor must depend chiefly on his own judgment, to lay out the work to the greatest advantage, according to the nature of the country, and other circumstances that will affect his operations.

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SECTION V.

METHOD OF CONDUCTING A SURVEY WITH THE
THEODOLITE.

It may now be of service, if I proceed to furnish an example of the most simple manner in which the survey of a tract of country may be commenced and carried forward. I shall suppose the survey such as might be wanted for military purposes, and that a small theodolite and common measuring chain are to be used. (Plate VIII.)

The selection of a base line is the first consideration; and, on examination, the direction of A B, along a piece of level ground, is found the most eligible. The next object is to choose commanding points for stations, so situated with respect to each other that good triangles may be formed; that is, sufficiently wide apart, and forming angles not too acute. These important matters being arranged, the base, A B, must be carefully measured three times over, and the mean taken, which is 3574 yards.

Marks, such as small flags, having been placed at C, E, and F, the most favourable points on the ridge running parallel to the river; also at H and G: the theodolite is set up at A, and the following angles taken, namely, C A E, C A F, C A B, B A G, and B A H. These may be entered in the field-book, thus:—

At A.

From C to E,	65° 50'	(Angle C A E.
C to F,	96 40	„ C A F.
C to B,	126 45	„ C A B.
B to G,	22 25	„ B A G.
B to H,	80 10	„ B A H.)

The instrument is then taken to the other end of the base, and angles are observed at B.

At B.

From A to E,	40° 20'	(Angle A B E.
A to F,	100 2	„ A B F.
G to H,	31 40	„ G B H.
G to A,	64 0	„ G B A.)

It should be observed, that when time permits, it is usual to take all such angles three times over, each time turning the circle of the theodolite, for greater correctness, and as a check against error. In this case, an entry would be made thus:—

At B.

	1st Obs.	2nd Obs.	3rd Obs.	Mean.
From A to E	40° 20'	40° 19'	40° 21'	40° 20'
A to F	100 2	100 1	100 3	100 2

With respect to the circle of the instrument, you may begin to work from any part of it; by which, should the dividing not be very perfect, the errors compensate each other; and to save time in the field, enter the readings as you obtain them from the circle, and work out the quantity for each angle at home. Suppose you commence taking angles, with the index showing 50° 10', the entries at B would be thus, to agree with the preceding example:—

Index at 50° 10'.	From A to E.		From A to F.	
	1st observ.	90° 30'	1st observ.	150° 12'
	2nd ditto	90 29	2nd ditto	150 11
	3rd ditto	90 31	3rd ditto	150 13
	Mean . . .	90 30	Mean . . .	150 12
	Deduct . . .	50 10	Deduct . . .	50 10
		40 20		100 2

The requisite angles having been observed from each end of the base, the instrument is moved to E, and angles taken, namely:—

At E.

From A to C,	59° 10'	(Angle A E C.
A to L,	87 0	„ A E L.
A to D,	142 30	„ A E D.)
A to M,	199 20	
A to F,	236 40	
A to B,	281 15	

Next move to C.

At C.

From L to D,	51° 20'	(Angle L C D.
L to E,	84 5	„ L C E.
L to A,	139 5	„ L C A.)

The instrument is then taken to F.

At F.

From B to A,	49° 53'	(Angle A F B.
B to E,	75 30	„ E F B.
B to D,	103 2	„ D F B.
B to M,	155 12	„ B F M.)

After which, angles are observed from other stations.

Previous to plotting, I recommend a diagram or figure to be drawn, representing the base line, and the several triangles; of these, it is a good plan to make a list, thus: *—

<i>Triangle A E B.</i>	<i>Triangle A C E.</i>	<i>Triangle A B F.</i>
Angle A, $60^{\circ} 55'$	Angle A, $65^{\circ} 50'$	Angle A, $30^{\circ} 5'$
B, 40 20	C, 55 0	B, 100 2
E, 78 45	E, 59 10	F, 49 53
180 0	180 0	180 0

To lay down the triangles: First draw a line on the paper, and take from the scale you intend to use, 3574, for the number of yards in the base; lay off this distance along the line, and one end of the length so marked on the line will be A, the other, B.

A consideration next arises whether the triangles shall be protracted by the sides or the angles; if by the sides, their lengths are worked out by means of plane trigonometry, and then laid down; for example: In the triangle, A B E, one side, namely the base, A B, is given, and the three angles; by means of which we are enabled to find the other two sides, A E and E B, by an application of the first case of trigonometry. The distances so found have then only to be taken from the same scale as the base, and the triangle, A E B, is easily constructed. Again, in the triangle, B E F, we have the side, E B (as just found), and the angles, to find E F and B F. Also in the triangle, A C E, the side, A E, has been found, which, with the angles, give A C and C E. The other triangles are ob-

* Two angles of any triangle being known, the third angle is their supplement to 180° .

tained in the same way. Thus, every side whose length is found becomes a base line for a succeeding triangle; and in this way a succession of triangles may be carried over the face of a country. Such is the method pursued in a regular trigonometrical survey.

But in a survey of small extent, and especially when time becomes an object of importance, the triangles may be protracted by the *angles*. Indeed, when the sides of the triangles do not exceed two or three miles, and the scale is not more than four inches to a mile, a good protractor of five or six inches radius enables us to lay down the triangles with sufficient accuracy and great despatch.

To commence, then, protracting by the angles: Referring to page 130, we find that, having the theodolite placed at A, our first set of angles was measured *from* C to E, F, and B; therefore, the first step now must be to fix the direction of C. To do this, we have only to look what angle is formed by C with the base, or in other words see how many degrees the angle is from C to B. Accordingly, we set the vernier of our semicircular protractor to $126^{\circ} 45'$ (page 130), namely, the angle C A B; and then place it so that its centre shall be at the point, A, while its straight base agrees with the base line, A B. A line is then drawn along the arm of the protractor, which line will determine the direction of C, forming an angle, C A B, of $126^{\circ} 45'$. This done, we are prepared to lay down the directions of E and F. The angle from C to E is $65^{\circ} 50'$; set the protractor to that quantity, but its position requires to be changed, as the straight base must now agree with the line, A C, while its centre continues, as before, at A. A line is now drawn, forming the angle, C A E; and in the same manner the direction of F is obtained, forming an angle, C A F, of $96^{\circ} 40'$. Next, for G and H, lay off from

$AB\ 22^{\circ}\ 25'$ for G , and $80^{\circ}\ 10'$ for H . Adjust the protractor on AB , with its centre at B , and lay off $40^{\circ}\ 20'$, the angle, ABE , and $100^{\circ}\ 2'$ for the angle, ABF ; draw lines, BE and BF , which will intersect AE and AF , thus determining the points E and F . Afterwards, draw GB , making an angle of 64° with AB , and on GB , as a base, set off $31^{\circ}\ 40'$ for the angle, GBH ; G and H will then be fixed by intersections with the lines, AH and AG .

Observe, when at A , the reason for taking angles from C towards B was to avoid the inconvenience of reading angles backwards on the horizontal circle of the theodolite, which would have been the case had we taken the angles to F , E , and C from B . The angles might, however, have been taken from B to G , then to H , and continued round to C , E , &c.; but the other way is most simple, and therefore easiest to be understood.

The angles taken at E are now to be protracted, together with those taken at C and F .

In the survey before us, we have E determined by observations from A and B . C , from A and E . F , from A , B , and E . D , from C , E , and F . The work then proceeds, taking the lines, AC , CD , DF , &c., as bases. Had it been desirable, we might have found the length of the line, EH , and worked from it as a base of greater length, and consequently, furnishing a foundation for larger triangles.

When a survey is of limited extent—say, from eight to twelve square miles—I would suggest that the base be laid down on a small scale, and the angles protracted with the ivory protractor in the field. This is quickly done, and will be found an advantageous method by persons who have not much practice in surveying, and who are consequently liable to make mistakes when they come to plot from a field-book alone; but doing this is by no

means to be understood as superseding the necessity of going over the whole protraction on a large scale, and more accurately afterwards.

After what has been said in the early part of the work, when treating of military sketching with the compass, it may be almost superfluous to dwell here on the manner of filling in these triangles; however, I shall say a few words upon the subject. Before entering into any details, I ought to observe, that in extensive surveys, what are called *secondary* triangles are always formed within the great triangles, so as to subdivide each of them into several smaller ones, affording stations carefully determined, for intersecting the various objects contained within their limits. But in the kind of survey we have been considering, where the sides of the triangles do not exceed two or three miles, this proceeding is not followed; and something like what I am about to describe would be practised.

Referring to the little example in the plate, the course of the river would probably first engage our attention in the filling in; to obtain which I should place marks, as a, b, c, d, &c., and intersect them from the ends of the base, or by taking angles or bearings from any of the points previously fixed on the plan. The mention of bearings reminds me that a meridian line has not yet been laid down; this is to be done while the theodolite stands at one end of the base, by observing how the other end bears, or by using any other fixed points for the purpose. For instance, we find that B bears from A $76^{\circ} 10'$ N.E. On the plan, then, it is only requisite to make the angle, $\angle A B$, $76^{\circ} 10'$, and the line, N S, becomes the magnetic meridian.

To return to the filling in of the survey; the points, f and k, the extremities of a little island, are fixed by angles from A, H, and E. To determine the situation of the

bridge, take a bearing from A, and measure the distance. Do the same at B, to find the position of d. Observe, that an experienced surveyor takes the bearing of every object likely to be of use to him in filling in, at every station where the instrument may be set up, as a little foresight often saves him the trouble and loss of time occasioned by the necessity of returning to a station.

The skeleton of a survey being carefully laid down to the required scale, and found correct, portions of it must then be transferred by tracing, to pieces of paper of a convenient size to use in the field with the sketching case; when the hills, and every required detail, are put in with the aid of a surveying compass; the method of using which instrument has been fully shown in Section III.

During the progress of a survey, advantage should be taken of any portion of level ground over which it may be carried, to mark off a convenient distance, which should be measured in precisely the same manner as that by which the length of the original base was obtained; then, a comparison between the length of such line, as measured, with its length on the plan—found either by computation, or by applying it to the scale used for the survey—will be a test of the accuracy of the work. A line measured for this purpose, is called a base of verification; and one or more, according to circumstances, should be made use of in all surveys.

Let me hope that enough has now been said to put the young surveyor on a right track to acquire a knowledge of the art. My opinion is, that a work on surveying, to be of any use, must enter very much into particulars. Properly to initiate the beginner has been my aim; and I have sought to effect this object in a way to be understood by any one of common intelligence, who will take the trouble to think. Ordinary surveying is a very simple process,

but to perform that process well requires both attention and experience.

I had almost forgotten to caution the student not to consider the examples given of military sketching and surveying as anything more than elaborate diagrams in illustration of the necessary descriptions; for instance, the method of conducting a survey, just described, is suited to a survey of twenty or thirty square miles, whereas the limits of our diagram do not contain more than six or seven.

SECTION VI.

ON PLAN DRAWING. — METHODS OF SHADING HILLS. —
VERTICAL AND HORIZONTAL STYLES.

WE have seen, in the foregoing sections, the manner of proceeding in the field, in order to obtain the necessary measurements of a survey. It has also been shown how those measurements are laid down on paper, or plotted, so as to furnish a rough skeleton plan of the work. I shall now speak of plan-drawing, in its more limited sense, or the method of expressing upon paper, according to certain conventional rules, the various objects which the face of a country presents, and that are required to be delineated by the topographical draftsman: but of these, the drawing of hills alone demands serious attention, for all the rest give us no difficulty whatever.

Objects having elevation can only be expressed upon a flat surface, such as paper, by means of shade, or by being thrown, as it is called, into *relief*; and consequently we can only give this appearance of *relief*, or being raised above the surface of our paper, in a ground plan, to bodies whose forms present either slopes or curves; unless we depart from the principles that govern a ground plan, and give an elevation to such bodies, in the manner seen on very old maps and plans; a practice which has universally been discontinued, since the introduction of the present system of plan-drawing.

A hill, therefore, presenting slopes, can, according to our conventional system of shade, be faithfully expressed on a

ground plan, so as to convey an idea of elevation to all who are acquainted with the principles of plan-drawing; but we are unable to give the appearance of elevation to a building, because its walls are perpendicular. In really, this is a matter of no consequence whatever, for the mind at once connects the idea of height with castles, churches, houses, &c.; and our method of shading hills, enables us, at the utmost, only to form a loose judgment of their height as compared to each other, for we cannot determine by it the actual elevation of any single hill. But for ordinary military purposes, an approximation to their *comparative* height is generally sufficient; and when for any particular object it becomes necessary to determine the actual elevation of any point above the sea, a river, &c., we can ascertain it either by *levelling*, or by a problem in the application of trigonometry to the measurement of heights; and likewise, but with less accuracy, by means of the mountain barometer.

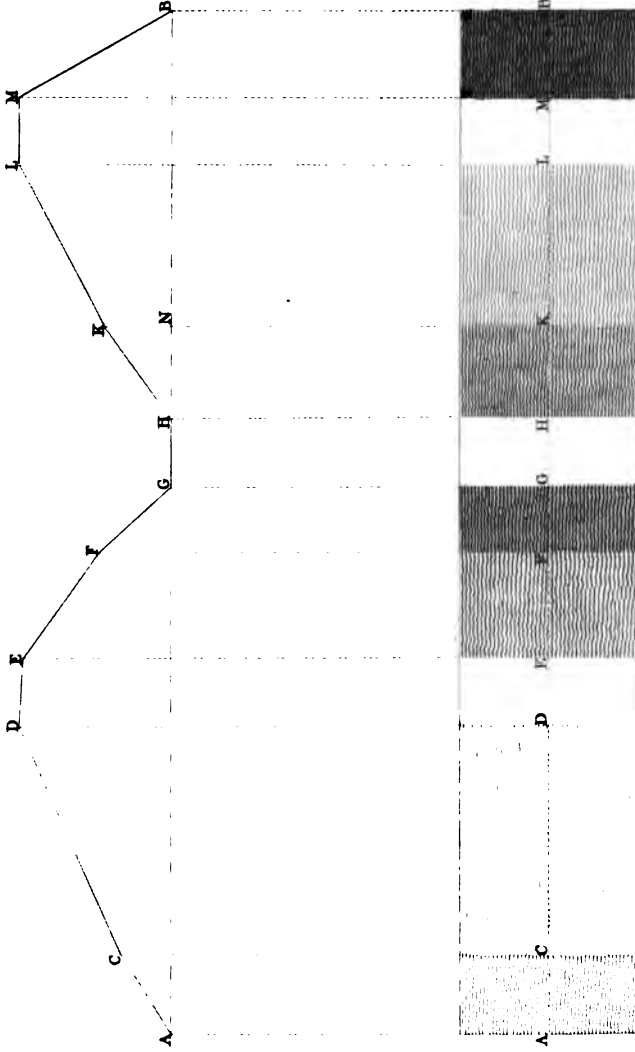
The theory most generally adopted, supposes the light to fall vertically upon the hills, in parallel rays; according to which steep slopes, receiving those rays at a more oblique angle than more gentle ones do, are therefore illuminated in a less degree than the latter, and must be shown in a plan by a darker shade; while such portions of the ground as are horizontal, and receive, consequently, the rays of light perpendicularly to their planes, being thus illuminated in the greatest degree, are left without shade in a plan; but, as it is scarcely possible to fix a criterion for the depths of tint in shading to express ground, it is idle to suppose that, *practically*, the shading can ever be so exact as to enable us to measure by it the positive height of a hill.

I fear it is almost impossible, by means of plans and descriptions, to convey at once to the mind of a student a

clear perception of our *conventional* system of expressing hills upon a plan; yet, if he will only have the patience to labour a little for himself, I think he may contrive to make it out. In the first place, he has to bear in mind that all distances shown upon a plan are horizontal ones; for instance, referring to plate IX., the line, H K, of the section, which is the hypotenuse of the right-angled triangle, H K N, is represented on the *ground plan* below by the line, H K, which is equal to H N in the section; and in same way, M B, a precipitous fall in the section, only occupies the space from M to B on the ground plan. Thus it is seen that the height of mountains or the depression of valleys exercises no influence upon the situations of objects in a plan. I may mention here that the level of the sea is, in great surveying operations, considered as the horizontal plane, to which all measurements must be reduced.

But as regards the expression of hills on a plan: suppose we are standing on one of a perfectly conical form, it is obvious that rain falling on its summit will trickle down towards the base in minute, diverging streams; — our vertical style of shading hills has been likened to these. The immediate purpose, however, of plate IX. is to show the principle upon which slopes are expressed by means of shade; which is made light or dark according as they are gentle or steep. The section given represents ground of varied character: A is on a level with the sea; from that point the hill has a steep rise to C, from whence it is somewhat more gentle as far as D; at E a descent begins, and continues to F, from whence there is a steep slope to G, and so on. I have endeavoured to make the shading of the ground plan to agree with the section: for instance, that from C to A is darker than between D and C. From D to E the ground is level, and therefore no shade appears.

Section on A. B.



Ground Plan

The slope from E to F, being greater than from D to C, is shaded darker : F G, being steeper, is made darker still ; and the deep shade from M to B is equal to the shading of both of the slopes, L K and K H.

I shall not fatigue my reader with any further description. He must now try and make out the corresponding parts of the ground-plan and section for himself. But perhaps he may stumble at the threshold, not-knowing what a section is ; the term profile would have been better, for that means a *vertical* section. It may serve to convey an idea of a profile of a hill, if the reader will call to mind the appearance it presents in hazy weather, when nothing but the outline is visible ; or, referring to the ground plan in plate IX., let him conceive the hills there represented to be cut away from the dotted line, A B, so as to leave the faces of the remaining parts of the hills perpendicular : these faces would then present the exact appearance of the profile give in the plate.

By a little attention to what has been said above, I think the student will be able to comprehend the nature of a ground-plan of a hill, with its corresponding section, as here shown.

METHODS OF SHADING HILLS ; VERTICAL AND HORIZONTAL STYLES.

The shading of hills may be performed by using a black-lead pencil,—with a pen,—by washes of Indian ink, or neutral tint, &c.

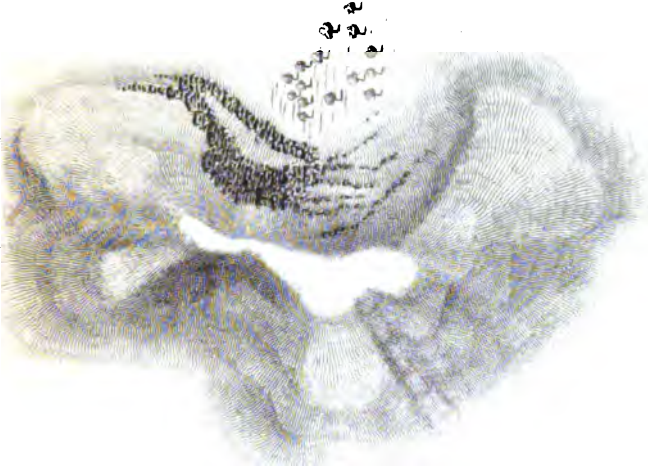
There are two modes of expressing inclinations of ground with the pen or lead pencil, distinguished as the vertical and horizontal styles. In this country, opinion is divided as to which method is the best for general purposes.

The examples given in the plates, hitherto, have all been in the vertical style of shading; adopted in my work, because I think, on the whole, that a beginner would find it easiest both to understand and execute; that it is the quickest for field-sketching, and has been the most generally practised.

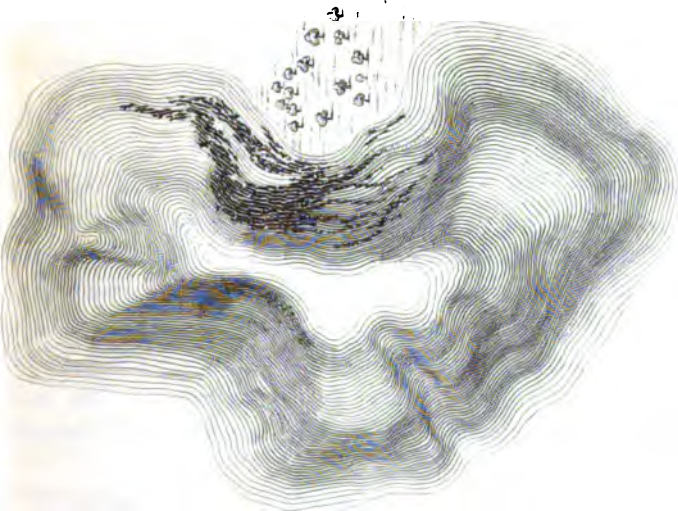
The *vertical* mode, as already stated, assumes the pen strokes to represent such minute rills as water forms when trickling down the slopes of a hill. The *horizontal* manner marks the contours of hills by waving lines, each line continuing on the same *level* while following every undulation of the ground; as, in some hilly parts of this country, sheep paths may be observed, often covering the entire faces of steep declivities, at a few feet apart, and horizontally pursuing the windings of the hills.

Mr. Burr, the Professor of Military Surveying at Sandhurst, showed me recently what I think a very ingenious and striking way of conveying a just idea of this style, by means of a model in plaster of Paris, representing some hilly ground. He had enclosed his model in a woden box, which was then filled with water. A scale, divided into quarters of an inch, having been placed upright in the box, the water was allowed to run off through a hole near the bottom, by a quarter of an inch at a time, as indicated by his scale. At every successive fall of the water, he traced lines on the model, indicating the curves shown upon its surface by the successive lowering of the water. When the operation was completed, the surface of his model exhibited a number of lines, all of course perfectly horizontal; closing upon each other where the hills were steep, and diverging again where the slopes became more gentle. A model so prepared is easily represented on paper, and with great accuracy; and I cannot do better than recommend those who are desirous to obtain a thorough knowledge of

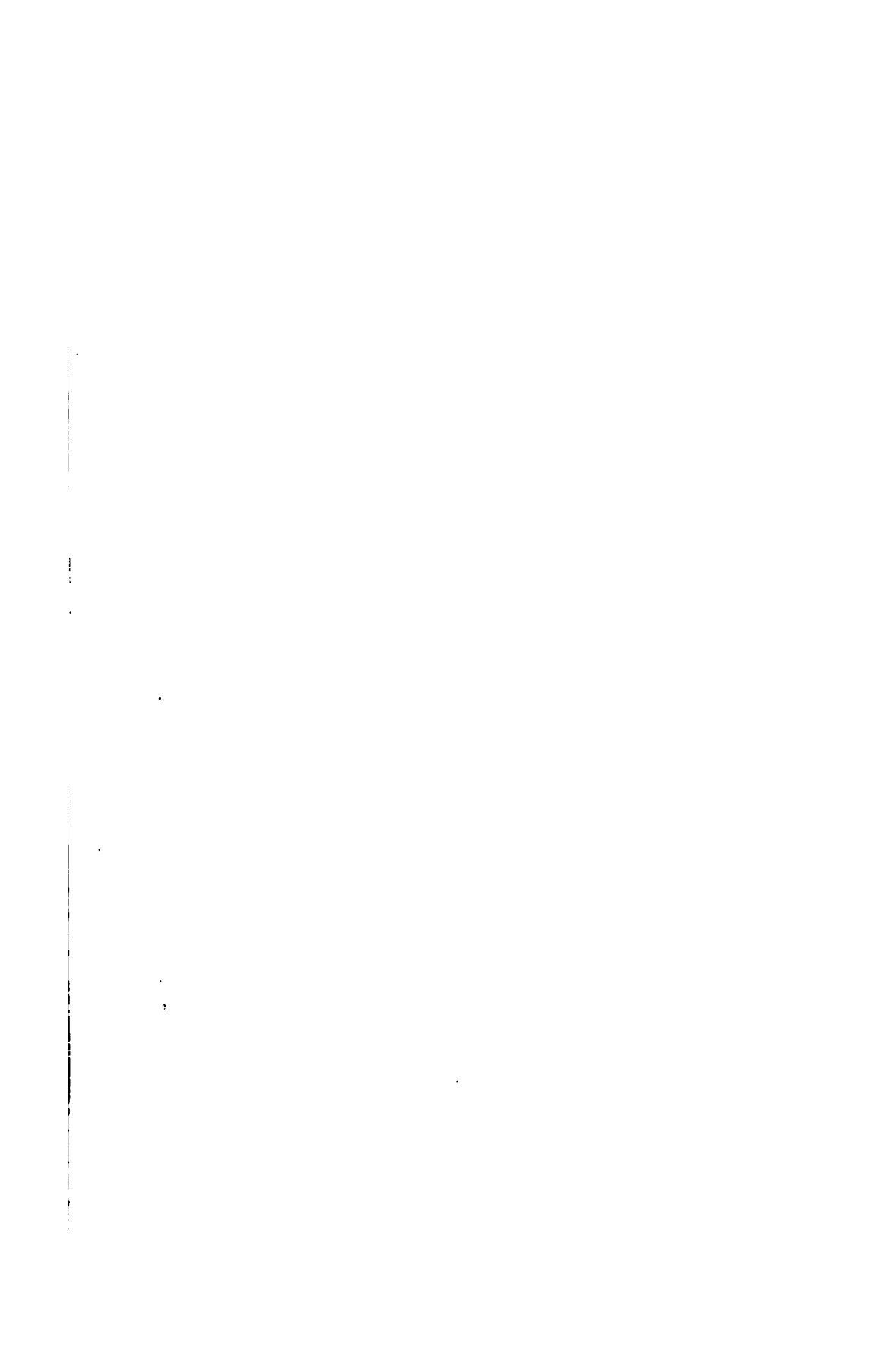
PLATE IX.



Vertical Style



Horizontal Style



ground, to consider the horizontal method with attention, as it reduces the delineation of hills to something of a fixed principle. In practice, either or both of the styles may be used at the pleasure of the draftsman, or as may be best suited to the nature of the ground he wishes to pourtray.

The vertical style of sketching hills used to be generally practised in the British service; so much so, that I do not think a single officer of the Royal Staff Corps employed the horizontal manner; but of late years the latter has been in favour at our military colleges, and now bids fair entirely to supersede the vertical method. A very able military surveyor, and possessing as much practical experience as any officer in our service, makes the following remarks on the two styles: *—"The features of ground were expressed formerly by curve lines, parallel to the horizon, covering the convex or concave sides. The modern, or, as it is termed for the sake of distinction, vertical style (written in 1827), is preferable, for several reasons, among which the following may be stated:—

"Roads deviate as little as possible from a horizontal plane: on a convex or concave surface they cannot continue in such a plane but in curvilinear directions. Roads amongst hills are, therefore, generally of this description; they would, consequently, be parallel to curve lines expressing the ground, and therefore not readily distinguished from them on a field sketch. In the vertical style, the road is parallel to the lines, only when its ascent is direct, which rarely occurs: when the direction is horizontal, each line will be crossed by the road at right angles. A diagonal direction will indicate an oblique ascent, propor-

* "Outlines of a System of Surveying," &c. By Lieut.-Colonel Sir T. L. Livingstone, Surveyor-General of New South Wales.

tioned to the angle with the lines and that of the direct acclivity.

“ Any proportion of stratified rocks on the side of a hill may be shown with effect, by strong characteristic touches across the vertical lines ; and also all other natural and artificial circumstances, which occur most frequently in planes parallel to the horizon.

“ There is another advantage in the vertical direction of the lines, which is, that it becomes the very style of the engraver, who cannot have too close a guide in the delineation of the ground, since that is a subject which admits of no deviation on the part of the copy, whether as to outline or shade ; while, as the loose character of the originals has hitherto been an insuperable bar to improvements in this branch of the art, any approximation in style between the draftsman and the engraver is very desirable.

“ The most common character of the sides of hills (as seen in profile) being that of a double curve, it is obvious that there is no particular part near the summit, or base, of such a form which could be selected as proper for the commencement of concentric circles, or curves, to represent that as it would appear under a vertical light. The first lines around the summit, and the last at the base, cannot easily be melted into that soft appearance of natural shade which is produced by lines radiating from the summit. The gradual termination of any of these is scarcely perceptible at the summit and the base, while the sensible breadth near the middle denotes the part most inclined to the horizon. By unevenness of termination, the peculiar form of any summit is expressed with softness, or its circularity is shown by the points of many lines without the stiffness of the circular line. Slight features at the base of a hill are also easily connected with it, by continuing the lines.

“ More may be expressed with fewer lines, in sketching according to the vertical style. Three or four divergent lines will mark the situation of a hill and the extent of its base; curves at a similar distance would show no connexion amongst other curvilinear lines, representing roads, &c.

“ The advantage of the vertical lines is still more apparent in representing ridges of that uniform character, which occur so generally in the Pyrenees and the Alps; the angle at which the lines meet the beds of torrents, expresses the direction and rapidity of their descent. Such are the reasons in favour of the vertical method of drawing the lines.”

If the student could procure a good model or two, with plans of them, he would derive great advantage from an attentive comparison of the latter with the former. He might then lay aside the plans, and endeavour to make others for himself from the models, which he could afterwards compare with the other plans. By such a practice, he would speedily attain to great facility in sketching, and the knowledge of ground: after which he might proceed to sketch from nature, which he would find very easy, owing to his previous course with models. Unfortunately, good models, and plans of them, are not easily procured; the student must, therefore, go at once to the field, and work from nature.*

The most rapid way of expressing hills upon paper, is by shading with Indian ink or neutral tint: for this, two camel-hair brushes are used, one to lay on the tint with,

* At the East India Company's Military College, very extensive modelling is practised with *wet sand*. This material was proposed for the purpose by Lieutenant Cook, F.R.S., Assistant Professor of Fortification at that Institution: it is found to answer admirably.

and the other for softening it down. A dexterous hand will, in this manner, speedily dash in the hills of a plan: but a few touches with a pen over the shading, enable an artist to give form to the features of ground with less labour than by brush-shading alone. All touches, however, that are introduced with no other object than to produce effect, are very objectionable. If rugged ground is to be pourtrayed, free touches become necessary; but the judicious draftsman will endeavour to suit his style to the nature of the hills he has to express: steep and broken declivities will admit of freedom in the touch, but smooth and gentle slopes must be made to preserve their proper character; and yet a proficient with the brush or pen, will always contrive to throw a certain degree of spirit into his performance, whatever may be the nature of the ground he is representing: but this is the result of much practice, combined with a natural taste for drawing.

I have already said that the rays of light are supposed to fall vertically upon the ground, and that the degree of shade used for expressing hills depends on the greater or less gradations of their declivities; that is, the more the slope of a hill recedes from the horizontal, the darker must be the shade. In order to give the effect of *relief* to plans of hilly ground, some draftsmen suppose the rays of light to come on a plan from the left hand corner; according to which supposition, one side of a hill becomes brightly illuminated, while its reverse side is cast into deep shadow. I have seen some very beautiful specimens of plan drawing executed in this manner, by which a surprising effect of relief was produced; but I dissent entirely from this method of representing ground, as being likely to lead to error in the reading of a plan; for having no means whereby to judge of steepness but by shade:—

remove that from one side of a hill, and we are left entirely to conjecture with respect to the slopes on that side. Undoubtedly our system of supposing the rays of light to fall vertically upon the hills, while all other objects, as rivers, houses, trees, &c., receive it obliquely from the left hand corner of the plan, is contradictory; but where all is conventional, the inconsistency is not felt as any inconvenience: and it may further be observed, that in general the object of giving shadow to houses, trees, &c., is chiefly as a finish, and for effect; although, in the plans of engineers and architects, it is essential.

ON PLAN-DRAWING.

I do not think it would be attended with any advantage to the student, were I to enter minutely into the details of plan-drawing. From description alone, I conceive it to be out of the question that any one can form a correct idea of the manner of executing a finished plan. A few hints on the subject may, however, be of service to the student.

For laying down plans, stout drawing paper is best. "Double elephant" is a useful kind, whose size is 36 x 28 inches.

All plans are first drawn with a black lead pencil; the lines are afterwards penned over with *Indian ink*; or colours are used when a highly finished plan is required.

The colours required for plans seldom exceed the following:—

1. *Indigo*.—A light tint of which is used to colour rivers and other waters.
2. *Gamboge*.—This colour mixed with indigo forms

green for colouring fields. All wood work is designated on plans by gamboge or some other yellow.

3. *Lake*.—Employed to represent masonry, as towns, houses, castles, bridges, &c.
4. *Burnt Sienna*.—Roads are commonly coloured with a light tint of this pigment.
5. *Indian Ink*.—For shading hills, drawing lines, &c.*

Plans are copied in various ways. The best is by tracing at a glass frame or window; for which purpose the paper intended to receive the copy is pinned to the original. When mounted on pasteboard, or other opaque substance, some other mode must be resorted to, as that of dividing the original plan into compartments or squares, by ruling lines upon it lightly with a pencil; similar squares are then formed on the paper, and the copying becomes easy. This latter method is employed for increasing or diminishing the size of the copy, as compared with the original. By using what is called tracing paper, through which the details of a plan are visible, a copy is speedily and very correctly made; and afterwards, if necessary, a tracing may be made from it upon thick paper at a window. There are also other methods, but the above are sufficient.

The student should be warned that the hygrometrical state of the atmosphere exercises great influence on drawing paper, which expands or contracts it so as materially to affect long lines on a plan.

* The student would find it convenient to have his Marquois scales and triangle, with the necessary mathematical instruments as mentioned at page 38, together with these few colours, and three or four camel hair pencils, to fit into a small box. This has been done in a compact manner by Messrs. TROUGHTON and SIMMS, 136, Fleet Street.

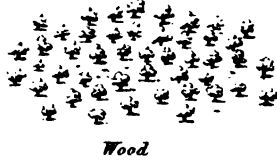
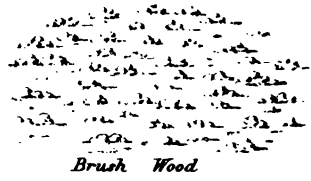
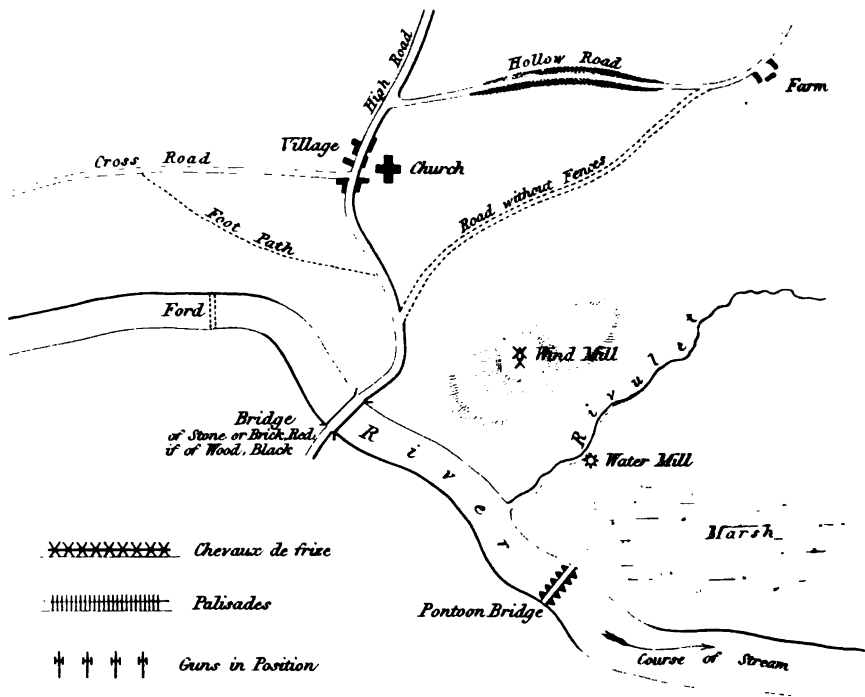


Plate X. contains the conventional signs in plan-drawing, which are generally employed: instead of multiplying these to an inconvenient extent, it is better to make memoranda on the plans. For instance, signs are sometimes used to denote whether a ford or a marsh be passable for troops; and even to point out whether practicable for infantry, as well as guns and cavalry; but, in my opinion, it is better to say, in language that cannot be mistaken, what description of ford it may be.

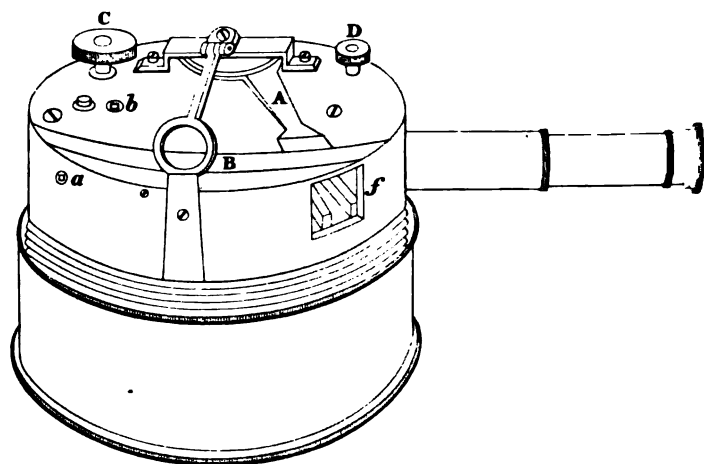
SECTION VII.

OF THE POCKET SEXTANT.—ITS ADJUSTMENTS.—USE IN
SURVEYING, MEASURING HEIGHTS AND DISTANCES, ETC.

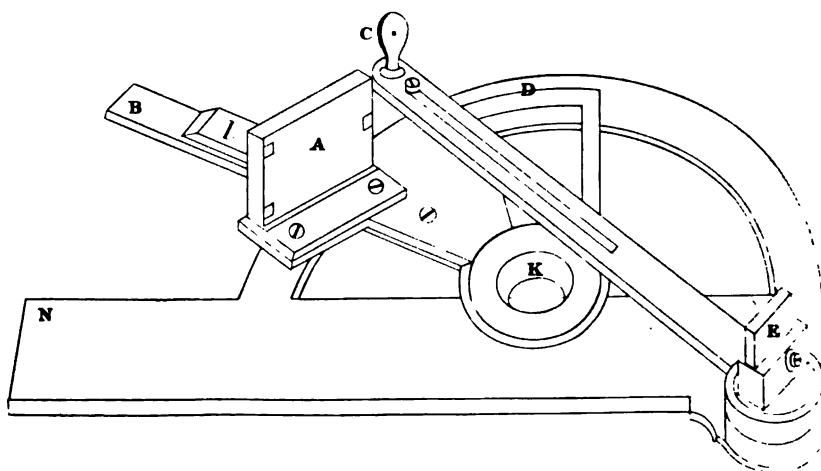
WITH a view of not distracting the attention of the student, little or no mention has been made thus far of any surveying instruments, save such as were absolutely necessary in order to illustrate our descriptions of the various methods of proceeding: but although we have hitherto confined ourselves to the theodolite and compass, it is not to be inferred that we reject all others. The pocket sextant and the reflecting semicircle, are both applicable to the purposes of military men, and may be advantageously used on many occasions instead of a theodolite or compass. We shall now proceed to give a particular description of the sextant, and to explain the several uses to which this beautiful instrument may be applied.

The pocket sextant combines numerous valuable properties; it measures an angle to one minute of a degree, requires no support but the hand, may be used on horse-back, maintains its adjustment long, and is easily re-adjusted when put out of order. It will determine the latitude by a meridian altitude to one minute, and an approximation may even be made with it to the longitude, by means of lunar observations. Further, it is very portable, forming when shut up a circular box under 3 inches in diameter, and only $1\frac{1}{2}$ inch deep.

The figure given in the plate represents the instrument screwed to its box, for convenience of holding in



THE BOX SEXTANT.



THE REFLECTING SEMICIRCLE.

the hand, and with the telescope drawn out.* A is the index arm, having a vernier adjusted to the graduated arc, B, which latter is numbered to 140° , but the sextant will not measure an angle greater than about 120° . The index is moved by the milled head, C, acting upon a rack and pinion in the interior. Two mirrors are placed inside; the large one, or index mirror, is fixed to and moves with the index; the other, called the horizon-glass, is only half silvered. The proper adjustment of the instrument depends on these glasses being parallel, when the index is at zero; while they are, at the same time, perpendicular to what is termed the plane of the instrument, represented by its upper surface or face. To observe whether the instrument is in perfect adjustment, remove the telescope by pulling it out, and supply its place with a slide for the purpose, in which is a small hole to look through; then place the index accurately at zero, and direct the instrument, holding it horizontally, towards the sharp angle of a building not less than half a mile distant, applying the eye so as to see both through the hole in the slide and also through the unsilvered part of the horizon-glass; the same object ought then to be so reflected from the index-mirror to the silvered part of the horizon-glass, as to seem but one with the object seen direct: if such be not the case, a correction becomes necessary, which is thus performed:—D is a key, removeable at pleasure, that fits two key-holes, the one at *a*, the other at *b*. Apply this key at *a*, and gently turn until the reflected object, and the one seen direct, seem but as one. The glasses are then parallel.

The next point is to examine whether the horizon-glass is perpendicular to the plane of the instrument. For this

* The telescope is unnecessary for ordinary distances: the instrument is sold either with or without it.

purpose hold the sextant horizontally, and look at the distant horizon; then, if any adjustment is wanted, two horizons will appear, and the reflected one will be higher or lower than the one seen direct: should this be the case, apply the key at *b*, so as to bring the two horizons together. It must be observed that the large or index-mirror, being correct by construction, it can want no alteration.

By looking at the sun, we can always satisfy ourselves with respect to the adjustments; the telescope has a dark glass at the eye end, and with this on we have only to place the index at zero, and, using the telescope, to look at the sun; when, provided the instrument is in exact adjustment, one perfect orb only will be seen. If the reflected image projects beyond the other, then correction is necessary. The full moon will answer as well as the sun for this purpose, but the dark glass at the eye end of the telescope must then be removed. The instrument is provided with two other dark glasses, which sink out of the way by raising two little levers at *f*.

It has been mentioned above that, for trying the adjustment of the sextant, an object must be half a mile off; this is on account of what is called the parallax of the instrument, occasioned by the necessity of placing the eye of the observer on one side of the index-mirror. Could we look from the middle of it, there would be no parallax; which is the angle subtended by the point of vision and centre of the index-glass, when observing any near object: consequently, as the distance of an object is increased, this angle diminishes, and at length becomes as nothing when compared with it. Half a mile is considered sufficient for all error to vanish, but at half that distance it is imperceptible.

To take an angle, the observer looks either through

the telescope or hole in the slide (having previously raised the levers of the dark glasses at *f*), at the *left* hand object, holding the sextant horizontally in his left hand; with his right he turns the milled head, C, until the other object, reflected from the index-glass, appears upon the silvered part of the horizon-glass: exactly covering or agreeing with the left hand object, seen direct through the unsilvered portion of the horizon-glass: the angle is then obtained by the vernier to one minute. Should circumstances render it desirable for the observer to look at the right hand object, he has only to hold the instrument bottom upwards.

If the required angle be a vertical one, the sextant is held in a vertical position by the right hand, while the left turns the milled head, C, until the object is brought down to the horizon.

When the altitude of a celestial body is taken at sea, it is brought down, as the term is, to the natural horizon, and the measure of the angle, or height of the object, is read off upon the graduated arc; but on land the natural horizon can seldom be used, on account of its irregularity: recourse is then had to what is called an artificial horizon, such as a vessel containing water, mercury, or other fluid. The observer then places himself in a situation to see the reflected image of the sun or other body in the fluid; he has only then to bring down the image, as reflected from the index-glass, until it reaches its reflection in the fluid: the altitude will then be *half* the number of degrees indicated by the graduated arc, subject to certain corrections, not necessary to be explained here.

The chief, and indeed only objection to the sextant, as a surveying instrument, arises from the angles taken with it not being always, like those measured by the theodolite and compass, *horizontal* ones. If the theodolite be set

truly level, we can take angles all round upon its circle, no matter whether one object be high and another low, and these angles will be what are termed horizontal angles; so that, were we to take angles from object to object and complete the circle, the sum of all those angles ought to be 360° , or the measure of a circle. But if the same angles were to be measured by a reflecting instrument, they would not produce precisely 360° , unless taken upon a perfectly level plane; owing to this circumstance, that to take an angle by the sextant, the two objects having to be brought into contract, namely, the reflected one and that seen direct, it is necessary for the observer to hold his instrument, not strictly horizontal, but in the plane of the two objects, or in such a position as will enable him to form the contract; and, therefore, if one point is elevated very much above the other, the sextant must be held at a corresponding inclination with the horizon. Angles so taken require a reduction, as it is termed, to horizontal ones; that is, to what those angles would have been, had the points subtending them been on a level with the eye of the observer, which is what is understood by the term horizontal. But as we seldom use the sextant to lay down points for a trigonometrical survey of importance, it rarely occurs that the reduction is required; indeed, to effect it with accuracy is attended with considerable difficulty, as the angles of elevation and depression must be known — a matter of no easy attainment with the sextant. It is better to avoid, if possible, the necessity of making any reductions, by selecting stations neither much elevated nor depressed; and three or four degrees either way can never affect an angle, so as to be of much consequence in common surveying. By a little management, too, a correct eye will enable us to select some spot directly under an elevated object, and at the same time

nearly horizontal; such mark may then be taken instead of the object itself: or we may take the angle between each of the objects we are observing, and some other point situated far to the right of them, and the difference will be an approximation to the angle sought. In short, a person habituated to the use of the sextant will generally be prepared with some contrivance, to obviate the necessity of having recourse to the reduction of his angles, which is performed, when requisite, by a calculation in spherical trigonometry.

An addition has lately been made to the pocket box sextant, for the purpose of taking altitudes and depressions: it consists of two small spirit-levels, fixed at the back of the horizon-glass, at right-angles to each other; so that, standing before the object, you look perpendicularly down through the plain sight, and moving the index, bring the image of the object to appear with the levels, which must have their air-bubbles in the centre of their tubes. The reading of the instrument will then show the supplement of the zenith distance, and its complement to 90° will be the angle required; elevated, if more than 90° , and depressed, if less than 90° . A moment's consideration will show that a practised hand is here necessary to catch the bubbles of such minute spirit-levels at the happy instant. This addition has the disadvantage of increasing somewhat the depth of the box, rather an objection in the eyes of military men. And after all, allowing that an approximation may be made by it towards determining an elevation or depression, when the object is very near, I feel certain that with distant ones, which necessarily subtend low angles, the result can never be depended on.

I may just notice here a contrivance for enabling the observer to read large angles with the box sextant — namely, by placing a second index-glass below the other,

and at right-angles to it; and having the arc doubly graduated, observations are then taken by looking through a different hole, placed opposite the usual one.

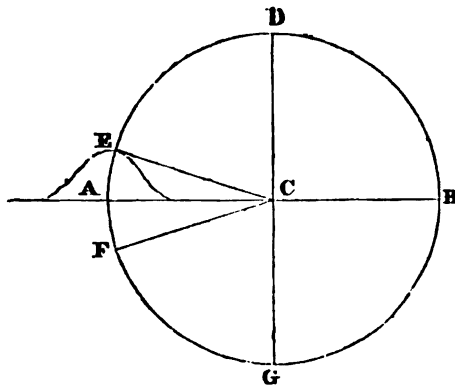
For military purposes, I object to this arrangement; as it reduces the index-glasses to half the original size, and therefore injures the instrument for distant observations.

In order to render this section on the sextant as useful as possible, I shall take the liberty of extracting from Mr. Burr's "Practical Treatise on Surveying and Topographical Plan-drawing," a little contrivance, that may be found useful.

"It has been said in the preceding pages, that reflecting instruments require an artificial horizon to take altitudes; but we cannot use them for small altitudes, because the rim of the vessel, containing the reflecting fluid, renders it impossible, nor can we take depressions by such means: yet, as a military man may have occasion for such observations, and not possess an instrument provided with a vertical arc and level, we shall show how this may be done nearly, that is to say, within two or three minutes, by a reflecting instrument. Place three strong stakes across, like the triangle used for hanging a kettle, upon the ground, binding them firmly at the junction; across two of the legs tie a fine thread tightly, and place underneath any vessel containing a fluid, as mercury or water. Now, it is plain, that when we look from above, so as to bring the thread and its reflected image into exact coincidence, our eye will be in a vertical plane; therefore, by resting upon the stakes, and bringing the reflected image of a distant object into exact contact with the thread, we shall measure the supplement of the zenith distance; and if that is less than 90° , its complement will be the depression; but if above 90° , the surplus will be the elevation.

This apparatus can be made any where ; and we insert this expedient, in order to show that, with apparently slender means, we may always do something."

I have found this simple expedient to answer very well for an approximation to the height of hills, buildings, &c., and shall add a diagram, which will assist my readers to understand it.



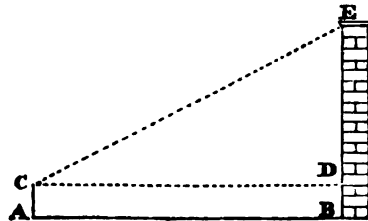
Let C represent the situation of the observers's eye, A B the horizon, and E the top of a hill: E D is then the zenith distance. By the method above given, we measure the angle, E C G, which is, of course, the supplement of the zenith distance, E D ; and, consequently, if we deduct 90° , or the angle, A C G, measured by the arc, A G—the angle, A C E, is left, namely, the elevation of E above the horizon. Again, for the depression—suppose our object is to obtain the depression of F—we measure the angle, F C G, the complement of which, or its difference from 90° , gives the angle, A C F, which is the depression of F.

MEASURING HEIGHTS AND DISTANCES.

The height and distance of objects, as walls or buildings, whether accessible or otherwise, may be obtained in a very simple and expeditious manner with the sextant, by means of the table of tangents, as follows:—

Multiplier.	Angle.	Angle.	Divisor.
1 . .	45° 0' . .	45° 0' . .	1
2 . .	63 26 . .	26 34 . .	2
3 . .	71 34 . .	18 26 . .	3
4 . .	75 58 . .	14 2 . .	4
5 . .	78 41 . .	11 19 . .	5
6 . .	80 32 . .	9 28 . .	6
8 . .	82 52 . .	7 8 . .	8
10 . .	84 17 . .	5 43 . .	10

Make a mark upon the object, if accessible, equal to the height of your eye from the ground. Set the index to one of the angles in the table, and retire on *level* ground, until the top is brought by the glasses to coincide with the mark; then, if the angle be greater than 45°, multiply the distance by the corresponding figure to the angle in the table; if it be less, divide; and the product, or quotient, will be the height of the object above the mark. Thus, let EB be a



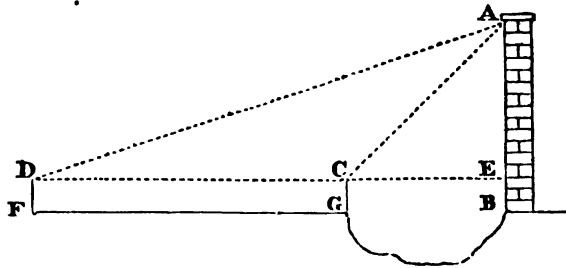
wall, whose height we want to know; and $26^{\circ} 34'$ the angle selected. Make a mark at D equal to the height of the eye; then step back from the wall, until the top at E is brought down by the glasses to coincide with the mark: measure the distance, A B, namely, from your station to the wall, and divide that distance by 2, the figure corresponding to $26^{\circ} 34'$, this will give the height, D E, to which B D must be added.

The *parallax* of the instrument has been already mentioned and explained: it exerts an influence on measurements of this kind, from the object being near. To correct it, we have only to ascertain its amount, by placing the index at zero, and looking through the instrument at the top of the wall; when, if influenced by parallax, it will appear as a broken line; but by moving the index a little way on the *arc of excess*, or to the left of zero, the broken line will reunite, and the adjustment be effected. When any quantity is taken thus on the arc of excess, the amount must be deducted, when setting the instrument to any of the tabular angles.

When the object is inaccessible, set the index to the greatest of the divisor angles in the table, that the least distance from the object will admit of, and advance or recede till the top of it is brought down by the sextant to level with the eye: at this place, set up a staff, equal to the height of the eye. Then set the index to one of the lesser angles, and retire in a line from the object, till the top is brought to coincide with the staff set up to indicate the height of the eye; place a mark here, and measure the distance between the two marks; this, divided by the difference of the figures opposite the angles used, will give the height of the object above the height of the eye, or mark. *For the distance*, multiply the height of the object by the numbers against either of the angles made use of,

and the product will be the distance of the object from the place where such angle was used.

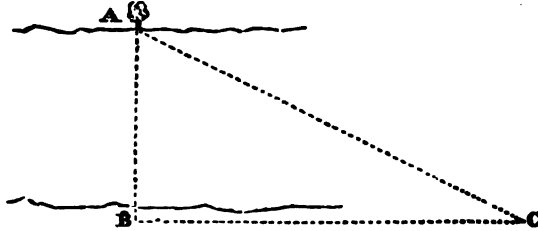
The above will be understood better by means of a diagram. Let AB be a wall, not to be approached nearer than C; and that we find, upon trial, that this distance admits of using the angle 45° : assume a point E on the wall, as the height of the eye; then the index being set to 45° , fix yourself so that the glasses shall bring the top, A, to coincide with E. At this point, place a staff, CG, equal to the height of the eye. Now select any one of the lesser angles from the tables— $18^{\circ} 26'$ for instance,



and retire until the point, A, agrees with the top of the staff, C G, which occurs at F. Place a mark at F, and measure the distance from F to G ; which, divided by 2, the difference of the numbers opposite to the angles used, will give A E : to which add B E = C G, the height of the eye, and the total height, A B, is obtained. Then, for the distance : the height, A E, multiplied by 3, its corresponding figure, will give the length, D E : and A E, multiplied by 1, will, in like manner, give G B = A E in this instance.

Horizontal distances, as well as heights, may be ascertained by means of the table, where the ground is level. Thus, suppose we wish to measure the breadth of a river, denoted by the line AB : set the index to an angle of the table, place a mark at B , and proceed in a direction, C ,

at right-angles to AB , until the glasses of the instrument show A and B in contact: then will the distance, AB , be



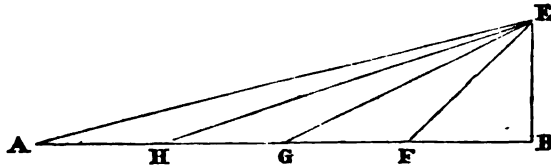
a product or quotient of the base, BC , according to the angle used. For instance, if the angle $26^{\circ} 34'$ be used, then must the distance, BC , be divided by 2.

The method of determining heights and distances by the tangent table is valuable, as the operations are speedily performed, and with tolerable accuracy; while it enables us to dispense with logarithmic tables and trigonometry.

The pocket sextant is very useful when taking off-sets: set the index to 90° , and walk along the station line; then, when you wish to ascertain at what point any mark or object becomes perpendicular to the station line, you have only to look through the sextant at the left-hand object, and move forward or backward until the two objects, namely, the off-set mark and that on your station-line, are brought to coincide. Or, if you wish to lay off a line at right angles to another, send your assistant with a staff in the required direction, and having set the index at 90° , cause him to move right or left until his staff and your other mark are made to agree.

The student ought to know the principle upon which the tangent table is formed. In the following figure, BE is perpendicular to AB ; and AH , HG , GF , and FB , are each equal to BE ; join EF , EG , EH , and EA . Then,—

M



- 1st radius : FB :: tangent $\angle F$: BE.
 2nd „ : GB, or 2 BE :: tangent $\angle G$: BE.
 3rd „ : HB, or 3 BE :: tangent $\angle H$: BE.
 4th „ : *EB :: tangent of the angle : BE.

Therefore,—

Natural Tangent.

$$\text{Tangent } \angle F = \text{radius} = 1. \dots = 45^\circ \ 0'$$

$$\text{Tangent } \angle G = \frac{\text{radius}}{2} = .5000000 = 26 \ 34$$

$$\text{Tangent } \angle H = \frac{\text{radius}}{3} = .3333333 = 18 \ 26$$

$$\text{Tangent } \angle A = \frac{\text{radius}}{4} = .2500000 = 14 \ 2$$

THE OPTICAL SQUARE.

Mention having been made at page 32 of the *optical square* for determining perpendiculars, and forming right angles on the ground, the following notice of it is extracted from Mr. F. W. Simms's Treatise on Instruments:—"In size it is not larger than a shallow circular snuff-box, which it resembles in shape. It is made of brass, and contains the two principal glasses of the sextant, viz. the index and horizon-glasses, fixed at an angle of 45° ; hence, while viewing an object by direct vision, another, forming a right angle with it at the place of the observer, will be referred by reflection, so as to coincide with the object viewed. Thus a line may be laid out perpendicular to a station-line, and from any point on it, by simply standing with the

instrument over the given point, and looking through it along the line, having a person to go with a mark or station-staff in the direction the perpendicular is required, and signing to him by hand to move to the right or the left, until his staff is seen, by reflection, to coincide with some object on the line along which the observer is looking, when the place of the staff will be in a perpendicular to the station-line at the place of the observer.

“ If it be required to find on a line the place of a perpendicular from a fixed object, as a house, &c., the observer himself must move along the line until the image of the object appears, as before, in the direction of the line, and the place where he then stands will be the spot where such perpendicular would fall.”

The optical square is so valuable a little instrument, that no surveyor ought to be without it.

ON LEVELLING.

SECTION VIII.

OBSERVATIONS.—LEVELLING WITH A MASON'S LEVEL.—
WITH BONING STAVES.—DESCRIPTION OF A SPIRIT-
LEVEL.—LEVELLING STAVES.—METHOD OF LEVELLING
WITH A SPIRIT-LEVEL.—DRAWING SECTIONS.

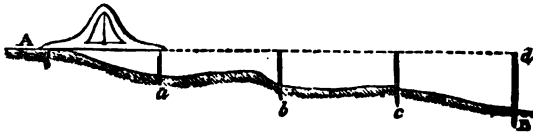
LEVELLING may be considered as a branch of surveying; a knowledge of it, therefore, is necessary for every surveyor. He may have to use a sloping base for a survey, which must be reduced to the true horizontal distance by levelling. Or he may have to drain a marsh; to form a road, either level, or with a certain degree of inclination; to take sections of ground for various purposes; to take profiles of fortifications and field works, &c. All such operations are performed by some kind of levelling process, as will be shown in the course of the following pages.

Writers on levelling generally commence the subject with the theoretical, and then proceed to the practical part; but I am of opinion that it would be better to set the pupil at once to work with his instruments, show him how to take levels, and thence lead him on to investigate the theoretical part. For instance, why perplex him with the spheroidal form of the globe, and its influence on levelling operations as occasioning calculations on account of curvature? Surely this, and the theory of refraction, had better be reserved until the student shall have obtained sufficient knowledge of levelling to take an interest in the

art; particularly as, in practice, corrections for curvature and refraction are very rarely applied; levelling operations being usually so managed as to render such corrections unnecessary.

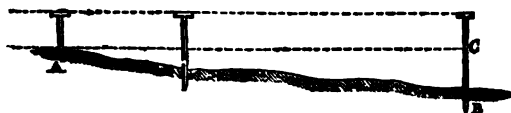
There are three kinds of levelling instruments in use, namely, the *ordinary Mason's level*, *Boning-staves*, and the *Spirit-level*. The two first are often employed when a spirit-level cannot be obtained; or for setting off slopes, and other minor purposes.

The method of using a mason's level is thus:—Suppose we want to know the difference of level between a point, A, and another at B. Drive a picket at A down to the



surface of the ground, and another, distant a few inches less than the length of the *level* at *a*, until the eye perceives that the head of the latter is nearly on a level with A; then set the *level* to rest on the two pickets, and the *plumb line* will show when their heads are truly level. A third picket is then driven in at *b*, a fourth at *c*, &c., to the heads of which the level is successively applied; and the length of the picket, B *d*, is the difference of level required: the heads of all the pickets will then be on the same level, represented by the dotted line, A *d*.

The same operation is more quickly performed by means of *boning-staves*, which are simply staves of equal length (usually three feet), having a T head. To level with their assistance, a mason's level is used for the first two pickets, as before; then a third picket being driven at any convenient distance, a *boning-staff* is held upon each, and the third picket is driven down until the observer at A can

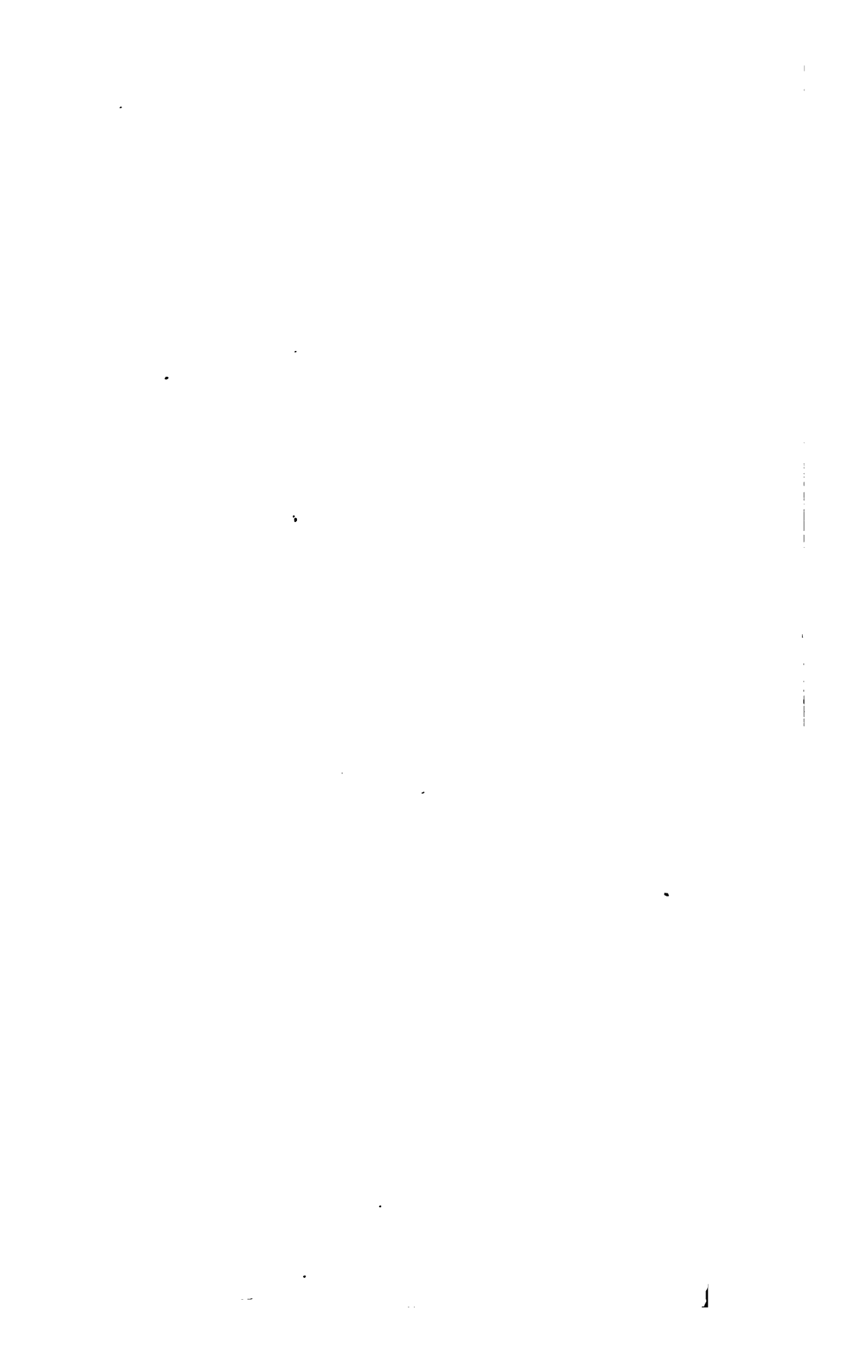


see that the upper surfaces of the T heads are all in an exact horizontal line: the operation may then be continued by driving in a picket beyond B, to which the boning-staff at A must be removed. Instead of driving a picket at B, a measuring-rod is often used, which being held perfectly upright a boning-staff is pressed against it, and caused to slide up or down, until its head agrees with those of the other two; when the difference of level is of course the distance between the foot, C, of the boning-staff, and B that of the measuring-rod. Observe that the boning-staves are to be held transversely, or at right angles to the position in which they are shown in the diagram.*

It is evident that levelling by means of a mason's level or boning-staves is only suited to very short distances; and they are but rough methods when compared to that by the spirit-level; for such is the accuracy of the process of levelling with a spirit-level, that an operation carried along a distance of several miles will not produce an amount of error equal to what will generally arise in the course of a few hundred yards, when using the former instruments.

Of spirit-levels, there are three now in use—namely, the Y level, Troughton's improved level, and Gravatt's level: these are all carefully described, and their several

* Engineers regulate slopes, by means of what is termed *Boning*. The operation is performed by driving a picket at the top, and another at the bottom of a given descent for the distance; upon these two boning-staves are held, while intermediate pickets are driven down until boning-staves, held on the heads of the latter, are seen to be in the same inclined plane with those placed at the top and bottom of the slope.



THE Y SPIRIT LEVEL.

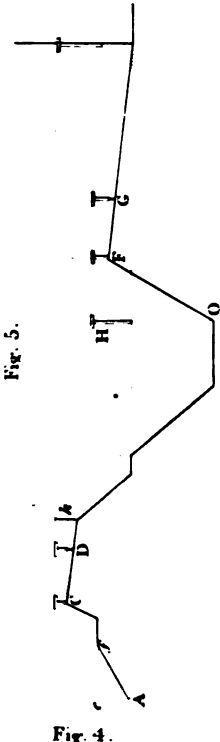
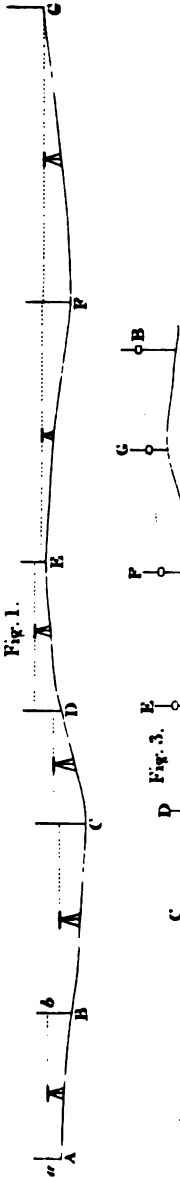
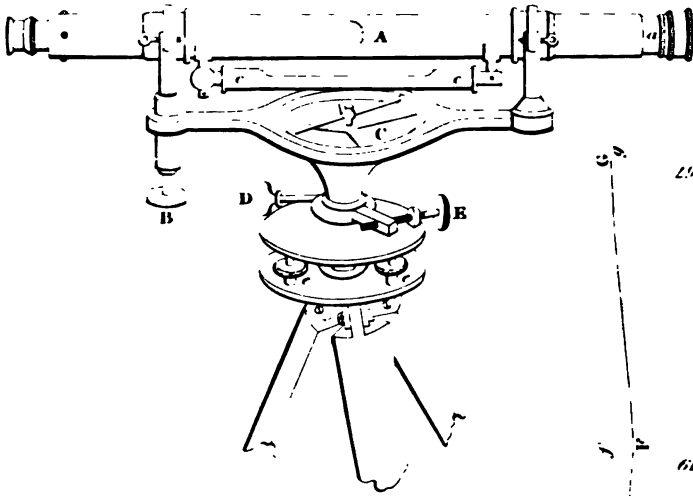


Fig. 5.

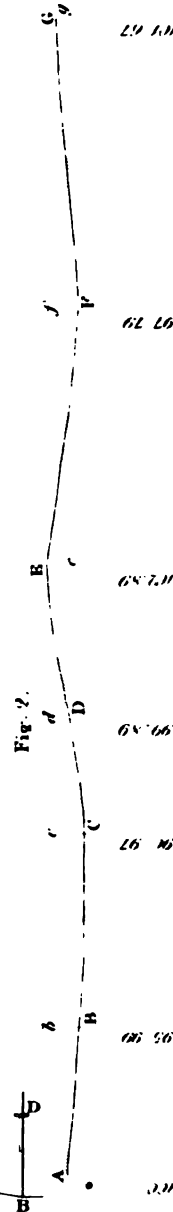


Fig. 7.

adjustments given, in Mr. Simms's work on instruments. I shall confine myself to the account of the Y level, as represented in the plate.

This instrument has an achromatic telescope, mounted in Ys, like those of the theodolite; and is furnished with a similar system of cross-wires, for determining the axis of the tube, or line of collimation. By turning the mill-headed screw, A, on the side of the telescope, the internal tube, *a*, will be thrust outwards, which carrying the object-glass, it is by this means adjusted to its focal distance, so as to show a distant object distinctly.

The tube, *c c*, carrying the spirit-bubble, is fixed to the under part of the telescope, by a joint at one end, and a capstan-headed screw at the other, which sets it parallel to the optical axis of the telescope. One of the Ys is supported in a socket, and can be raised or lowered by a screw, B, to make the telescope perpendicular to the vertical axis. Between the two supports is a compass-box, C (having a contrivance to throw the magnetic needle off its centre when not in use): it is convenient to take bearings, and is not necessarily connected with the operations of levelling, but extends the use of the instrument, making it a circumferenter. The whole is mounted on parallel plates, and three legs, the same as a theodolite.

It is evident from the nature of this instrument, that three adjustments are necessary. First, to place the intersection of the wires in the telescope, so that it shall coincide with the axis of the cylindrical rings, on which the telescope turns; secondly, to render the level parallel to this axis; and lastly, to set the telescope perpendicular to the vertical axis, that the level may preserve its position while the instrument is turned quite round upon the staves.

•

TO ADJUST THE LINE OF COLLIMATION.

The eye-piece being drawn out till the wires are distinctly seen, direct the telescope to any distant object, and by the screw, A, adjust to distinct vision;* bring the intersection of the cross wires to coincide with some well-defined part of the object, then turn the telescope round on its axis, as it lies in the Ys, and observe whether the coincidence remains perfect during its revolution: if it does, the adjustment is correct: if not, the wires must be moved one-half of the quantity of error, by turning the little screws near the eye-end of the telescope, one of which must be loosened before the opposite one is tightened, which, if correctly done, will perfect this adjustment.

TO SET THE LEVEL PARALLEL TO THE LINE OF COLLIMATION.

Move the telescope till it lies in the direction of two of the parallel plate-screws, *ee* (the clips which confine the telescope in the Ys being laid open), and by giving motion to the screws, bring the air-bubble to the middle of the tube, shown by the two scratches on the glass. Now reverse the telescope carefully in its Ys, that is, turn it end for end; and should the bubble not return to the centre of the level as before, it shows that it is not parallel to the optical axis, and requires correcting. The end to

* The eye-piece must first be drawn out until the cross wires are perfectly well defined; then the object-glass moved till distinct vision is obtained without parallax, which will be the case if, on looking through the telescope at some distant object, and moving the eye sideways before the eye-glass, the object and the wires remain steadily in contact; but if the wires have any parallax the object will appear fitting to and from them.

which the bubble retires must be noticed, and the bubble made to return one half the distance, by the parallel plate-screws, and the other half by the capstan-headed screw at the end of the level; when, if the halves have been correctly estimated, the air-bubble will settle in the middle in both positions of the telescope. This, and the adjustment for the collimation, generally require repeated trials before they are completed, on account of the difficulty in estimating exactly half the quantity of deviation.

TO SET THE TELESCOPE PERPENDICULAR TO THE
VERTICAL AXIS.

Place the telescope over two of the parallel plate-screws, and move them (unscrewing one while screwing up the other) until the air-bubble of the level settles in the middle of its tube; then turn the instrument half round upon the vertical axis, so that the contrary ends of the telescope may be over the same two screws, and if the bubble again settles in the middle, all is right in that position; if not, half the error must be corrected by turning the screw, B, and the other half by the two parallel plate-screws, over which the telescope is placed. Next turn the telescope a quarter round, that it may lie over the other two screws, and make it level by moving them; and the adjustment will be complete.

Before making observations with this instrument, the adjustments should be carefully examined and rectified, after which the screw, B, should never be touched; the parallel plate-screws alone must be used for setting the instrument level at each station; and this is done by placing the telescope over each pair alternately, and moving them until the air-bubble settles in the middle. This must be repeated till the telescope can be moved quite round upon

the staff-head, without any material change taking place in the bubble.

OF THE LEVELLING-STAVES.

Two mahogany station-staves generally accompany the spirit-level; they consist of two parts, capable of being drawn out, when considerable length is required. They are divided into feet and hundredths, or feet, inches, and tenths; and have a sliding-vane, with a wire placed across a square hole in the centre, as shown in the annexed figure; the vane being raised or lowered by the assistant

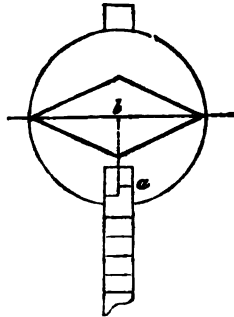


until the cross wire corresponds with the horizontal wire of the telescope, the height of the wire in the vane, noted on the staff, is the height of the apparent level above the ground at that place.

When both the staves are used they should be set up at equal distances on each side of the spirit-level; the difference of the heights of their vanes will be the absolute difference of level between the two stations. But when one staff only is employed, the difference between the height of the vane and the height of the centre of the telescope of the instrument will be the apparent difference of level; which, if the distance between the staff and instrument is great, requires to be corrected for the curvature of the earth.

TROUGHTON'S LEVELLING-STAVES.

These consist of three sliding rods of mahogany, each four feet long, and they are divided into feet, &c., as those which have just been described. The sliding-vane is circular, having at the lower edge a square aperture, one



side of which is bevelled; and a line on the bevelled side denotes the reading of the staff. The face of the vane is made of white holly, with an inlaid lozenge of ebony, forming at once a conspicuous object and one easy of bisection. A circular spirit-level is attached to the top of the hindermost rod, to guide the assistant in holding it perpendicular.

In levelling, the vane must be moved up or down, until the horizontal wire of the telescope bisects the acute angles of the lozenge; or, in other words, passes through its horizontal extremities, as shown in the figure.

A line on the bevelled edge at *a* (as before stated) denotes the reading of the staff; therefore a piece equal in length to the distance, *a b*, is cut off from the bottom of the staff, or rather, the divisions commence at that number of inches above 0.

When the observation requires that the vane be raised

to a greater height than four feet, the object is effected by leaving it at the top of the rod in front, and then sliding this rod up upon the one which is immediately behind it; this will carry the vane up to eight feet, and from that to twelve may be obtained by similarly sliding the second upon the third rod. In the latter steps the reading is at the side of the staff, the index division remaining stationary, and at four feet from the ground; a circumstance which affords great facility in reading off.

The Troughton staves, although exceedingly well-contrived and very portable, are liable to some objections, the principal of which is, that the observer must depend on his assistant to read the height observed; or, if he is not sufficiently intelligent to be entrusted with so responsible a duty, he is obliged, after the observation is made, to carry the staff to the observer, or to wait for him to come and read off the height of the vane and register it in his field-book; thus occasioning great loss of time and uncertainty in the results, for the vane on the staff might possibly be shifted in the meantime. Also, when very dry, I have found the slides to slip down one or two tenths of an inch, notwithstanding every care on the part of the assistant to hold his staff steadily: a remedy has been found for these defects in

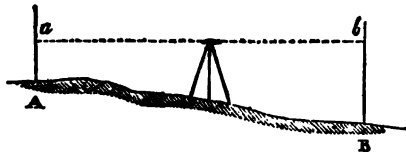
THE NEW LEVELLING-STAVES.

These have no vane to slide up and down, but the face of each staff is made broad enough to contain sufficiently large graduations and figures, for the observer to read with certainty to the one-hundredth part of a foot, at the distance of seven or eight hundred feet, which is sufficient for most practical purposes; thus securing greater certainty and expedition in the work: for it not unfre-

quently happened, in using the old staves, that when, by a succession of signals, the staff-holder had nearly brought the wire of the vane to coincide with that of the telescope, he would, in his attempt to perfect it, remove the vane further from coincidence than at first.

The newly constructed staff consists of three parts, which pack together for carriage in a neat manner; and when opened out for use form a staff seventeen feet long, jointed together something after the manner of a fishing-rod: the whole length is divided into hundredths of a foot, alternately coloured black and white, and occupying half the breadth of the staff; but for distinctness the lines denoting tenths of feet are continued the whole breadth, every half foot or five tenths being distinguished by a conspicuous black dot on each side.

We shall now proceed to show how the difference of level is ascertained, between two points, A and B, a distance we will suppose of five hundred feet. Plant the spirit-level about mid-way between the stations, taking care to press its legs firmly in the ground; draw out the eye-piece



of the telescope until the cross-wires appear perfectly well-defined; then directing the telescope to a levelling-staff, held at one of the stations, turn the milled-head, A, until the smallest graduations on the staff can be seen with clearness:* that these two adjustments be very carefully and completely performed, is of more consequence than

* We suppose the new levelling-staves to be used.

is generally supposed, for upon them depends the existence or non-existence of instrumental parallax.

Having made the above adjustments perfect, bring the spirit-bubble into the centre of its glass tube, which position it must retain unmoved in every direction of the instrument; or, in other words, the bubble must indicate a true level during the time the telescope is turned completely round horizontally on its staff-head: this is accomplished by bringing the telescope successively over each pair of the parallel plate screws and giving them motion, screwing up one while unscrewing the other to a corresponding extent, in the manner pointed for the adjustment of the theodolite, page 100.

The level being now prepared for observation, an assistant holds up the staff at A, either resting it on the ground, or what is better, upon a peg driven down to its surface: he must be careful to hold it perpendicularly. The observer now directs his telescope upon the staff, and when nearly in the right direction let him turn the clamping-screw, D, after which, by means of the slow-motion screw, E, the telescope is adjusted with greater exactness upon the staff; when the number of feet, and parts of a foot, are to be carefully noted, as cut by the horizontal wire of the telescope, and represented by *a* in the figure, the dotted line, *a b*, representing the line of sight or visual ray. The assistant then places his staff on a peg at B, and the observer (taking care to notice that the bubble of his level continues in the centre of its tube), directing his telescope, reads off as before. We will suppose that the reading with the staff at A was 3 feet and 9 hundredths of a foot, and that the reading with the staff at B was 7 feet and 11 hundredths; then the difference of level between the two stations is obtained by subtracting the less from the greater. The difference here is 4 feet and 2 hundredths.

The above is an example of simple levelling, when the stations not being more than six or seven hundred feet apart, and the inclination of the ground slight, one operation is sufficient. But when, from the distance or great steepness, several similar operations are necessary, it is called compound levelling, and a register or field-book is required to enter the observations in.

Let us now suppose a case of compound levelling, and the proceeding will be as follows—to ascertain the difference of level between two points, A and G, see plate, fig. 1.

Plant the spirit-level, as before, about mid-way between A and a point B, at any convenient distance, which need not be exactly in line between those points. Then the instrument being carefully adjusted, we will suppose that when directed to A, the reading on the staff A *a* is 3·07 feet, and when turned to B, that it is on the staff B *b*, 7·08 feet. The instrument being then successively placed at convenient situations between BC, CD, DE, EF, FG, let us suppose that the readings on the staves held up at A, B C, &c., are, as entered in the field-book below:—

<i>Back.</i>	<i>Forward.</i>
A 3·07	B 7·08
B 4·03	C 9·05
C 10·00	D 1·08
D 8·02	E 5·02
E 2·10	F 7·20
F 6·09	G 2·21
33·31	31·64
31·64	

1·67, that G is above A.

The sum of all the back readings being greater than that of the forward ones, the latter is deducted from the former,

which gives 1·67 feet as the difference of level between the points A and G.

Such is the easy process, whatever the distance or nature of the ground; whether a continued descent or of an undulating character: and if a section of the ground between the points is not required, the most convenient line for the operation may be selected. But when a section is to be made, the distances between the several stations must be carefully measured, and the rises and falls of the ground reduced to the true horizontal lengths; this reduction had better be made during the operation, in order that the column of distances in the field-book may show the horizontal ones, and thus save trouble when the section is to be drawn.

The following method of obtaining the horizontal length of a slope will be found to answer very well for short distances. Let one end of a measuring tape be held close to the ground at the upper station by an assistant; you then descend to the length of the tape, or less, if the slope be considerable, and elevate the other end, at the same time drawing tight, until the stretched tape is horizontal; when a small stone being dropped, the point where it falls will be the position from which the next measurement is to commence. But for long distances, especially when the ground rises or falls with regular slopes, it will be found better to measure the length of a slope, and afterwards reduce it to the true horizontal distance by calculation. When, however, the rise or fall is very slight, the reduction may altogether be disregarded; the difference between the hypotenusal and horizontal measurements being scarcely perceptible. (See page 84.)

The following little table will be useful in making reductions :—

Rise in feet for one hundred.	Reduction upon one hundred feet in feet and decimals.
1	0·01
2	0·02
3	0·05
4	0·08
5	0·13
6	0·18
7	0·24
8	0·32
9	0·40
10	0·50
11	0·61
12	0·72
13	0·85
14	0·98
15	1·14
16	1·29
17	1·45
18	1·63
19	1·82
20	1·93

When an operation of levelling is performed for the purpose of obtaining a section, the form of a field-book, as follows, will be found very convenient. We shall insert the levels as in the former field-book.

LEVELLING FIELD-BOOK.

Back.	Forward.	Dist- ance.	Difference.		Reduced Level.	
			Rise.	Fall.		
A 3·07	B 7·08	320		4·01	— 4·01	below A.
B 4·03	C 9·05	406		5·02	— 9·03	ditto.
C 10·00	D 1·08	240	8·92		— 0·11	ditto.
D 8·02	E 5·02	318	3·00		+ 2·89	above A.
E 2·10	F 7·20	548		5·10	— 2·21	below A.
F 6·09	G 2·21	625	3·88		+ 1·67	above A.
33·31	31·64		15·80	14·13		
31·64			14·13			
1·67			1·67			

The sign — (minus) prefixed to the 4·01 in the column of reduced levels, signifies that the point B is 4·01 feet below A: the same sign continues with the two following entries, showing that C is 9·03 feet, and D, 0·11 feet below A: but E we find to be 2·89 feet above A, and the sign + (plus) is used to denote that it is so.

The figures in the last column are obtained by addition or subtraction, as the case may require: for instance, we find that when our instrument is placed between A and B, that B reads 7·08

and A 3·07

4·01 difference — fall.

Again, between B and C the difference of level is 5·02; the ground still falling, this must be added to the 4·01, making a total fall from A to C of 9·03 feet.

From C to D there is a rise of 8.92 feet, which quantity being deducted from 9.03, brings the levelling up to 0.11 feet of the level of A; and the rise continuing to E, which is 3 feet above D, we have (by deducting 0.11 feet that D was below the level of A) the level of E 2.89 feet above A; and so on.

It is a proof that the field-book has been correctly kept, when the difference between the totals of the back and forward stations, and that between the totals of the rises and falls, agree with the last reduced level: thus, by reference to the above example of a field-book, it will be seen that this condition is fulfilled; 1.67 feet appearing in the proper columns as the height of G above A.

TO DRAW THE SECTION.

Rule a straight line, *Ag* (see plate, fig. 2), to represent an horizontal line at the level of A; this is termed a *datum line*: along it, set off *Ab* equal to 320 feet, namely, the *horizontal* distance from A to B, as entered in the field-book: from the point *b*, let fall a perpendicular, and make *bB* = 4.01. Join *AB*. Take *bc* = 406 feet, and make the perpendicular, *cC* = 9.03 feet. Join *BC*. In the same manner proceed with the *section*, letting fall or raising perpendiculars, *dD*, *eE*, &c., according as the field-book entries carry the section below or above the datum line, *Ag*.

In setting off on the datum line, each distance separately (as above described), you carry forward whatever error may have been made in taking any of them from the scale. To do away with this source of error, it is better to add the measured lengths together, each to the sum of those preceding it; thus obtaining the absolute length of every

station from the starting point; and by setting them off in this way, the height of each will be placed on the section in its correct relative situation; and should an error be committed in marking off any point, it does not affect the rest.

If the foregoing method of reducing levels be found difficult or troublesome, on account of the introduction of plus and minus signs, they can be dispensed with, as well as the columns of "Rise" and "Fall," by proceeding in the following manner:—Assuming the starting-point to be any even number of feet high; or, what is the same thing, assume a datum line any even number of feet below the starting-point, as 100; taking care that your choice falls upon a number greater than the number of the whole fall you are likely to experience in the operation; then from this assumed height *subtract* the reading of the forward, and to the remainder *add* the reading of the back-staff, the result will be the height of the first forward station above the assumed datum line; then from this height subtract the next forward reading, and to the remainder add the reading of the back-staff, the result will be the height of the second forward station above the assumed datum; and so on throughout the whole levelling operation. The difference between any two of the readings will be the difference of level between the corresponding points on the ground.

By way of illustration, we will reduce part of the foregoing example after this manner, and the student can then adopt whichever method he may consider the best.

Back Sight.	Forward Sight.	Reduced Levels.	REMARKS.
3·07	7·08	100·00	Assumed datum.
		7·08	
		92·92	
4·03	9·05	3·07	Height of 1st former station [above assumed datum.
		95·99	
		9·05	
10·00	1·08	86·94	Ditto 2nd ditto ditto.
		4·03	
		90·97	
8·02	5·02	1·08	Ditto 3rd ditto ditto.
		89·89	
		10·00	
2·10	7·20	99·89	Ditto 4th ditto ditto.
		5·02	
		94·87	
6·09	2·21	8·02	Ditto 5th ditto ditto.
		102·89	
		7·20	
7·		95·69	Ditto 6th ditto ditto.
		2·10	
		97·79	
		2·21	
		95·58	
		6·09	
		101·67	

If, after adopting the latter mode, it should be required to reduce the levels to that of the starting point as a datum, nothing more is required than to take the difference between the height thus found, and that of the assumed datum: thus, in the above example, subtracting 95·99, the height of the first forward station, from 100 (the assumed datum), we have 4·01 for its height below the starting point: next, taking 90·97 from 100, leaves 9·03 for the quantity that the second forward station is below the level of the starting-point; and so of the rest. Or it may be done much easier after the section is made to the assumed datum, by drawing a line parallel thereto through the point, A, or any other that may be determined on: thus, the section may be at once adapted to any required datum line.

Fig. 2, in the plate, also shows the mode of drawing a section, according to the latter way of keeping the register. *h o* represents the datum line; *h i, i k, k l, &c.*, the distances from station to station; perpendicular lines, *h A, i B, k C, &c.*, being drawn to *h o*; *h A* is made 100 feet (the assumed datum), *i B* 95·99, the height of the first forward station above the assumed datum; *k C* 90·97, the height of the second forward station above datum; and so on.

It may here be observed, that when a section is made of a considerable length of ground for railway, canal, or other purposes, two scales are used, one for the horizontal distances, the other for the vertical heights and depths, which produce a caricatured representation of the country; but by making the vertical scale much larger than the horizontal one, the depths of cutting and embankment required in the execution of road, railway, or canal works, are shown with greater clearness than if both scales were equal. Civil engineers usually take 4 inches to a mile for the horizontal scale, and 100 feet to one inch for the vertical one.

When a section of a line of country has been completed (for any purpose whatever), it is in most cases necessary to check its accuracy by repetition; but in doing this it is seldom requisite to level over precisely the same line of ground, unless there is cause to suspect its general correctness, but to follow the most convenient and nearest route, and at intervals to level to some known points on the exact line of section, which will give *their* difference of level: the points thus selected are generally what are called *bench* marks, and are nothing more than marks or notches cut upon gate-posts, stumps of trees, mile or boundary stones, or any similar immoveable objects, contiguous to the line of section, and at frequent intervals. These bench marks are made by the person who takes the section in the first instance, and are sometimes previously determined upon. When the section is complete, their relative heights with regard to the base line, or datum of the section, become known; consequently, they may be considered as so many zero or fixed points on the line, easily recognisable, from whence any portion of the work may be levelled over again; or branch lines of level may be conducted in any direction, and the levels of such branches be comparable with those of the main line.

LEVELLING WITH A THEODOLITE.

The use of the theodolite, as a levelling instrument, consists in taking a series of angles of elevation and depression along the line, the section of which is required. To do this, it is only necessary to set the instrument up at every spot on the line of country to be levelled, where the inclination changes, without regard to the minor in-

equalities of the surface, taking care that the adjustments have been carefully examined and rectified, especially those which set the line of collimation and the spirit-level attached to the telescope parallel to each other. Then set the instrument level, by means of the parallel plate-screws; and direct an assistant to go forward with a staff, having a vane or cross piece fixed to it, exactly at the same height from the ground as the centre of the axis of the telescope. Having gone to the forward station, the assistant must hold the staff upright whilst the observer measures the vertical angle, which an imaginary line, connecting the instrument and staff, makes with the horizon; the instrument and staff must then change places, when the same angle should be taken back again, and the mean adopted as the correct result.

The distance must then be measured, which it will be evident is the hypotenuse of a right-angled triangle; the perpendicular of which is the difference of level to be obtained by calculation from the following

RULE. Add together the logarithm of the measured distance and the log-tangent of the observed angle; the sum, rejecting ten from the index, will be the log. of the difference of level in feet, or as the distance was measured in.

In this manner, by considering the surface of every principal undulation as the hypotenuse of a right-angled triangle, the operation of levelling may be carried on with great rapidity; but with less accuracy than by the spirit-level.

Another method of applying a theodolite to the purposes of levelling, is to set up the instrument at the foot of an inclination; thus, suppose the theodolite placed at A, fig. 3 (see plate), and the telescope elevated so that the line of sight, A B, may coincide with the vane on a staff,

exactly at the same height from the ground as the instrument; suppose the staff held at B, the angle of elevation being carefully noted, the instrument must remain perfectly steady, whilst the observer is watching an assistant passing along the line with a staff, which he successively holds up at every change of inclination, as C, D, E, &c., the staff-holder raising or lowering the vane until the observer perceives the cross wires of the telescope (or line of sight, A B) to coincide with that on the vane; the height of the staff is then read off and noted, which gives the depression of that spot of ground below the line, A B; which being done along the whole distance, and a mark made on the ground at each spot, that the distances may likewise be measured, the undulations of the surface below the line, A B, is determined, and the inclination of the line of sight being likewise obtained with the theodolite, the requisite data for drawing the section are obtained: and it will easily be seen that, when the ground is irregular, the section will be obtained with greater exactness when the stations, or points where the staff is held up, are very numerous.

After having obtained the difference of level from station to station, either with a spirit-level or theodolite, the rate of inclination of the surface may be found by dividing the distance by the difference of height: thus, if the distance be 760 feet, and the height 38 feet, 760 divided by 38 gives 20; showing the rate of inclination to be 1 in 20.

Probably sufficient has now been said, as regards the practical part of the subject, to enable a student to understand and practice all ordinary levelling operations; but one or two examples of the methods pursued by military men, when taking sections for the purpose of profiling and defilading field-works, &c. &c., may be useful.

1. We will suppose that, for some military object, it is necessary to ascertain the difference of level between the crest of the parapet, A, and the foot of the glacis, B (see plate, fig. 4); and that the following implements only are at hand, namely, a 10-feet rod, two boning-staves of 3 feet, a staff of similar form, that is, with a T head of 6 feet, and a mason's level.

Drive a picket at C, and level the top of it with the point, A, by the mason's level. Next send a man to the foot of the glacis at B, and let him hold up the 10-feet rod, against which he must slide the 6-feet staff, until the top of it, D, is found to be on a level with the boning-staves held at A and C; when it is evident that the point to which the head of the staff at D reaches along the 10-feet staff, deducting 3 feet (length of the staff at A), will be the difference of level required.

2. We will suppose that a section of a field-work is to be made by means of the same implements. Fig. 5.

Here it is only necessary, after the head of a picket driven at D is made level with the point, C, to cause an assistant to hold up the 10-feet rod at the foot of every slope, along which he is to slide the 6-feet boning-staff, until it appears on a level with the staves held up at C and D. The horizontal length of each slope is easily determined by resting the 6-feet staff on the level part at the bottom, taking care to hold it perpendicularly, while the 10-feet rod is applied in an horizontal position, as from *e* to *f*, *c* to *h*, &c.

Should the bottom of the ditch be too low for the long rods to reach up to the level of the staves at C and D, the level of the crest of the glacis at F may be taken, and a picket driven at G to the level of F, when the length, H O, may be observed.

With a spirit-level it would only be necessary to plant

the instrument on the banquette at *f*, and hold up the regular levelling-staff at the foot of each slope, as described above.

To draw the section it will merely be requisite to rule a line, and having set off upon it the horizontal lengths of the several slopes, let fall perpendiculars from the points obtained, along which distances are to be taken corresponding with the levelling.

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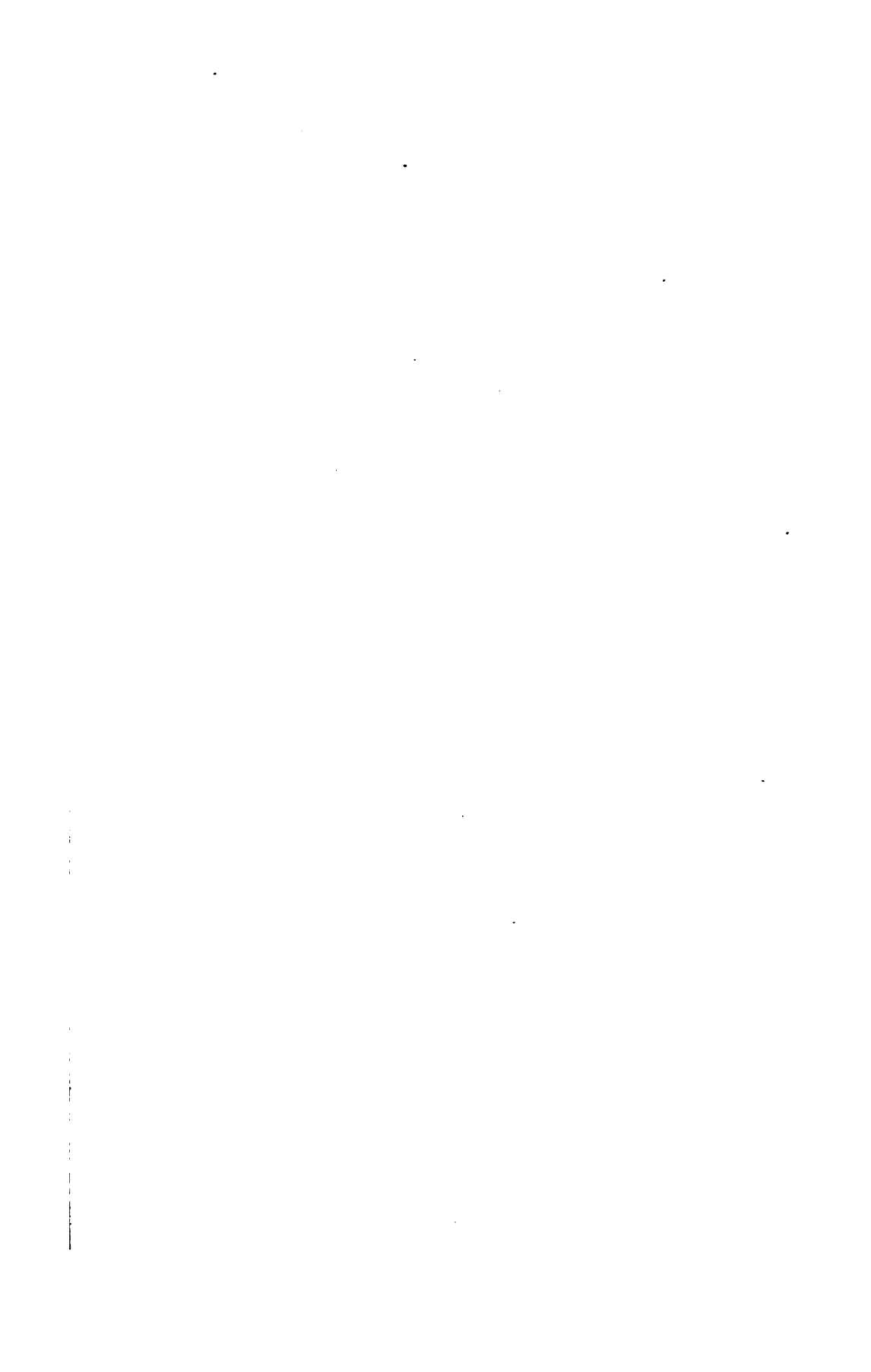
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